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400ppm	Acronym for a Mitigation Scenario leading to a stabilization of CO2eq. concentration of 400ppm until 2100
450ppm	Acronym for a Mitigation Scenario leading to a stabilization of CO2eq. concentration of 450ppm until 2100
A	Year
ABS	Agent-based simulation
ACER	Air Conditioning Equipment Rate
ACT	Annual circulation tax
ACUEC	Air Conditioning Unit Energy Consumption
ADAM	Adaptation and Mitigation
ADAM-HMS	ADAM hybrid model system developed in our work package M1
AFR	Africa
AFV	Alternative fuel vehicles
Alterra	Alterra Institute at Wageningen University
ASTRA	Assessment of transport strategies model
AT	Austria
AVRES	Air conditioning Availability
BCS	Biomass for thermal electricity with sequestration
BE	Belgium
BG	Bulgaria
BGA	Hydrogen from biomass gasification
BDZ	Bundesverband der deutschen Zementindustrie e.V.
BGS	Hydrogen from biomass gasification with sequestration
BGT	Biomass gasification for electricity production in GT
Bio	Billion (1*10^9)
BM	Biomass
BPY	Hydrogen from biomass pyrolysis
BRA	Brasil
BSR	BSR Sustainability GmbH
BTE	Biomass for thermal electricity
BUM	Bottom-up Models
CAN	Canada
CCGT	Combined cycle gas turbine
CCS	Carbon capture and sequestration, Carbon caption and storage
CCT	Cross-cutting technologies
CCT	Coal powered Conventional Thermal

CDD	Cooling Degree Days
CDM	Clean Development Mechanism
CEPI	Confederation of European Paper Industry
CGA	Hydrogen from Coal Gasification
CEMBUREAU	The European Cement Association
CEPI	Confederation of European paper industries
CGS	Hydrogen from Coal Gasification with sequestration
CHN	China
CHP	Combined heat and power technologies
CHP	Combined Heat and Power (small to medium)
CIS	Countries of the Independent States
CMAX	Climate Maximum Saturation Rate
CPIV	Standing Committee of the European Glass Industry
CNG	Compressed natural gas
CO2	Carbon dioxide
COP	Conference of the parties of the UNFCCC
CSP	Concentrating solar power
CY	Cyprus
CZ	Czech Republic
D1	ADAM deliverable D-M1.1 [Jochem et al. 2007] describing the applied models and the base case scenario
D2	ADAM deliverable D-M1.2 [Jochem et al. 2009] describing the reference scenario (adaptation case) and a 2-degree scenario until 2100
D3	This deliverable of ADAM work package M1
DE	Germany
DK	Denmark
DPV	Decentralised building integrated PV systems with network connection
DWL	Number of Dwellings
E3MG	global energy-environment-economy model
East	European country group: Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia
EC	European Commission
EE	Estonia
EEAP-NL	Heat recovery and intermediate storage
EFISCEN	European Forest Information SCENario model
EJ	Exa Joule
ENV	Environment Module
ES	Spain
ETS	Emission trading system

EU	European Union
EU27	European Union with 27 member states as of 2007
EU27+2	EU27+Norway+Switzerland
EUCoun	ASTRA index of countries
Euro-MM	A bottom up optimisation model simulating the energy conversion ector
EUROPE	Europe
FAOSTAT	Statistical Database of the Food and Agriculture Organisation of the United Nations
FCCELRESC	Air Conditioning Electricity Consumption with Climate Change Impact
FCSENRES	Final Consumption for Substitutable Energy in Residential Sector
FOT	Foreign Trade Module of ASTRA
FEBELCEM	
FI	Finland
FR	France
GC	Generalised Cost
GDP	Gross domestic product
GGC	Gas powered Gas Turbine in Combined Cycle
GGS	Gas powered Gas Turbine in Combined Cycle with sequestration
GGT	Gas powered turbine
GHG	Greenhouse gases
GIS	Geographical information system
GR	Greece
GSR	Hydrogen from Gas Steam Reforming
GSS	Hydrogen from Gas Steam Reforming with sequestration
Gt	Billion tons
GVW	Gross vehicle weight
H/C days	Changes of heating and cooling days
HDD	Heating Degree days
HDV	Heavy Duty Vehicles
HMS	Hybrid model system – ADAM approach of integrating macro-economic and bottom-up models
HU	Hungary
HVAC	Air conditioning system
HYD	Conventional large size hydroelectricity
ICG	Integrated Coal Gasification with Combined Cycle
ICS	Integrated Coal Gasification with Combined Cycle with sequestration
IDA-ICE	A dynamic building simulation model
IE	Ireland
IFP	Institut Français du Pétrole

INF	Infrastructure Module of ASTRA
IPCC	Intergovernmental Panel on Climate Change
ISIndustry	A bottom up model simulating the energy demand of the industrial sector
IT	Italy
IWW	Integrating Inland Waterways
JAP.PACIFIK	Japan & Pacific
JI	Joint Implementation
LA	Latvia
LCD	Liquid Cristal sector
LCT	Lignite powered Conventional Thermal
LDV	Light Duty Vehicles
LED	Diode lighting
LEPII	National Centre for Scientific Research, Energy and Environmental Policy at CNRS
LPG	Liquefied Petroleum Gas, transport fuel
LT	Lithuania
LU	Luxemburg
MARKAL	MARKet ALlocation
M1	Mitigation 1 work package (Europe)
M2	Mitigation 2 work package (Global)
MAC	Macroeconomics Module of ASTRA
MATEFF	A bottom up model derived from material efficiency simulating the reduced demand of energy-intensive basic products
MEPS	Minimum energy performance standards
MIEA	Middle East
Mio	Million (1*10^6)
MT	Malta
MWh	Mega Watt hours
NDE	India
NGV	Natural Gas Vehicles
NHT	Hydrogen from nuclear thermal high
NL	Netherlands
NMS	New Member States
NND	New Nuclear Design
North	European country group: Denmark, Finland, Norway, Sweden
NUC	Conventional Light Water nuclear Reactor
OD	Origin Destination Pair
OCT	Oil powered Gas Turbine in Combined Cycle

OECD	Organization for Economic Cooperation and Development
OGC	Oil powered Gas Turbine in Combined Cycle
OPO	Hydrogen from Heavy Fuel Oil Partial Oxidation
PFC	Pressurised coal supercritical
PJ	Peta Joule
PKM	Passenger-km i.e. 1 person transported over 1 km = 1 pkm
PL	Poland
POLES	Prospective Outlook on Long term Energy Systems model
POP	Population Module
POWER-ACE - ResInvest	Agent-based simulation model simulating the development of renewable energies
PPM	Parts per million
PPP	Purchasing power parities
PSI	Paul Scherrer Institute
PSS	Pressurised coal supercritical with sequestration
PT	Portugal
PV	Photovoltaics
R&D	Research and Development
RASIAJ	Rest of Asia
REF	Acronym for the Reference Scenario (adaptation, no mitigation)
Region	EuroMM index of countries
REM	Regional Economics Module of ASTRA
RES	Renewable energy sources
RES-E	Renewable energy systems for electricity generation
RESAPPLIANCE	A bottom up model for all electrical appliances including ventilation and air conditioning
RESIDENT	A bottom up model for heating and warm water generation in the residential sector
RET	Renewable Energy Technology
RLAM	Rest of Latin America
RO	Romania
RoW	Rest-of-the World
SFOE	Swiss Federal Office of Energy
SE	Sweden
SERVE-E	A bottom up model simulating the energy demand of the service and agricultural sector
SHT	Hydrogen from solar thermal high
SHY	Small Hydro Power plants (<10 MWe)
SI	Slovenia

SK	Slovakia
SME	Small and medium sized enterprises
SMR	Hydrogen from Solar Methane Reforming
South	European country group: Bulgaria, Greece, Italy, Malta, Cyprus, Portugal, Romania, Spain
SPP	Solar Power Plants (thermal technologies for network electricity production)
SFOE	Swiss Federal Office of Energy
TEN-T	Trans-European-Transport-Networks
TKM	Ton-km i.e. 1 ton transported over 1 km = 1 tkm
TRA	Transport Module of ASTRA
TTW	Tank-to-Wheel
TWh	Tera Watt hours
UCAM	Enerdata and Cambridge University
UNFCCC	United Nations Framework Convention on Climate Change
UEC	Unit Energy Consumption
UK	United Kingdom
URS	Ultimate Recoverable Resources
VFT	Vehicle Fleet Module of ASTRA
USGS	US Geological Survey
VDP	Verband Deutscher Papierfabriken e. V.
VDZ	Verein Deutscher Zementwerke e. V.
VKT	Vehicle-kilometres travelled
VMS	Virtual Model Server
VRT	Vehicle registration tax
WEG	Hydrogen from Water Electrolysis baseload electricity from Grid
WEM	Welfare Measurement Module
WEN	Hydrogen from water electrolysis nuclear dedicated
West	European country group: Austria, Belgium, Luxemburg, France, Germany, Ireland, Netherlands, Switzerland, United Kingdom
WEW	Hydrogen from Water Electrolysis dedicated Wind power plant
WND	Wind power plants for network electricity production
WNO	Offshore Wind power plants
WP	Work package
WTO	World Trade Organization

Executive Summary

Authors: Wolfgang Schade, Eberhard Jochem

ADAM research identifies and appraises existing and new policy options that can contribute to different combinations of adaptation and mitigation strategies. These options address the demands a changing climate will place on protecting citizens and valuable ecosystems – i.e., **adaptation** – as well as addressing the necessity to restrain/control humankind's perturbation to global climate to a desirable level – i.e., **mitigation**.

Our work package Mitigation 1 (M1) has the **core objective to simulate mitigation options and their related costs for Europe until 2050 and 2100 respectively**. **The focus of this deliverable is on the period 2005 to 2050.** The longer-term period until 2100 is covered in the previous deliverable D2, applying the POLES model for this time horizon [Jochem et al. 2009].

Our analysis constitutes basically a techno-economic analysis. Depending on the sector analysed it is either directly combined with a policy analysis (e.g. in the transport sector, renewables sector) or the policy analysis is performed qualitatively as a subsequent and independent step after the techno-economic analysis is completed (e.g. in the residential and service sectors). We start from the policy framework developed for mitigation of climate change by the EU and the Member States which can be summarised by the following broad options of climate mitigation policy:

- Introduce greenhouse gas (GHG) emissions trading,
- Increase of energy efficiency,
- Focus on renewable energies,
- Set standards and norms that drive technological development,
- Include all sectors and all greenhouse gases in the mitigation efforts, and
- Establish policies to directly stimulate low carbon technologies.

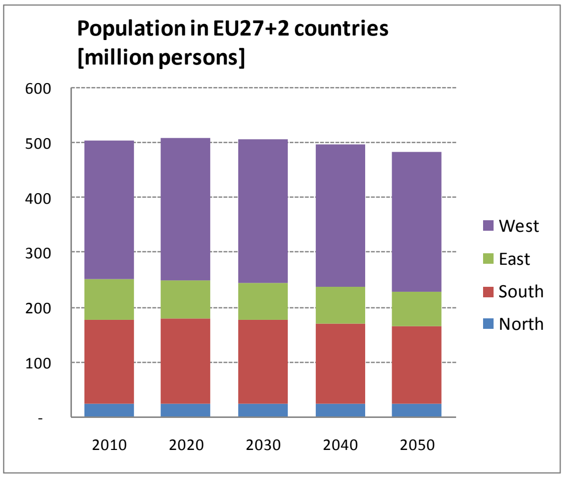
This framework is followed as well in our analysis throughout this deliverable: our assessment is that it would provide a suitable framework to drastically reduce the GHG emissions in Europe by 2050. The details of technologies and policy measures to fit into this framework and to complete the picture of climate policy are presented in this report on a sector-by-sector base for the residential sector, services sector, manufacturing sector, transport sector and energy conversion sector. This comprehensive sectoral analysis is then fed into a macro-economic model to assess the impacts on growth and employment of the proposed climate policy programme. Finally, the potential impacts of the economic crisis on the climate policy programme are discussed.

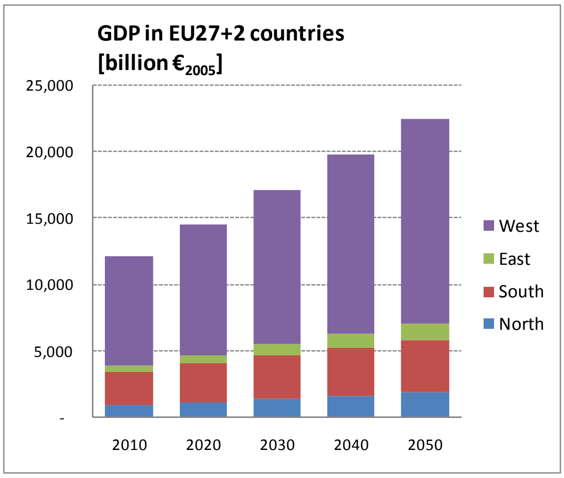
Scenarios to 2050

We estimate results of two variants of a possible 2-degree scenario with target concentrations of CO_2 of 450ppm (the **450ppm scenario**) and of 400ppm (the **400ppm scenario**). These two scenario variants are compared with the **Reference Scenario** [see Jochem et al. 2009], which constitutes a scenario with climate change of +4°C until 2100, i.e. an adaptation scenario.

The work on "Mitigation for Europe" is embedded into the larger framework of the ADAM project, in which also the "Mitigation on Global Level" is analysed. The global analysis provided a pathway of allowed GHG emissions of Europe for our work taking into account the mitigation activities at the global level and thus providing guidance on the efforts Europe has to contribute. Roughly, Europe starts its GHG emissions pathway from about 4000 Mt $CO_{2eq.}$ emissions in 2010 and reduces it to below 1000 Mt $CO_{2eq.}$ in 2050. This GHG pathway was used as a benchmark into which the aggregate sectoral GHG emissions in our analysis have to fit.

Figure 0-1 presents the development of two major drivers in the scenario: population and GDP. Population is the same in all scenarios, while GDP is an endogenous outcome of the scenarios and thus differs. Population is declining slightly until 2050 (-4%). The potential labor force decreases by -13% due to ageing of the European population and assuming stable retirement ages. GDP is expected to increase by +85% in real terms by 2050 compared with 2010 in the Reference Scenario. Oil prices are expected to increase by +90% by 2050 compared to 2010.





Source: ASTRA model reflecting the ADAM scenario framework.

Figure 0-1: Population and GDP framework in the Reference Scenario

Methodology

The research integrated bottom-up models with top-down models and developed the so-called ADAM Hybrid Model System (HMS). The basic concept underlying the ADAM-HMS is based on the following arguments: (1) it is feasible to link different types of models (e.g. top-down macro-economic and bottom-up techno-economic sectoral models), (2) it makes sense to link these models as each has specific strengths, and (3) the linkage of the models is more than the sum of the single pieces since it alleviates the limitations of the models by considering feedbacks that can not be considered just within one of the models.

An alternative to the linkage of separate models is the integration of the functionality within one model. Such an approach is taken by the POLES world energy system model, which besides a macro-economic model integrates all models of the ADAM-HMS into one integrated bottom-up model. Thus our work also included a comparison of the hybrid model system with the integrated approach for the energy system delivered by POLES.

Bottom-up techno-economic analysis

The bottom-up analysis included eight sectors/fields: forestry and energy crops, material efficiency, residential sector, services sector, industry sector, transport sector, renewables and energy conversion sectors. Each of the sectors contributed savings of (final) energy demand and GHG emissions. The aggregate pathways of final energy demand in ADAM-HMS (left-hand side) and POLES (right-hand side) for the 400 ppm scenario are shown in Figure 0-2. Both final energy demand pathways shown in this analysis require stringent policies and support to be able to meet the targets set by the European Commission. In the ADAM-HMS, the support would have to start earlier and concentrate on fostering renewables and efficiency technologies, while, in POLES, efficiency policies play a much smaller role and priority is given to the use of biomass and to carbon removal technologies, i.e. foster R&D and the introduction of CCS.

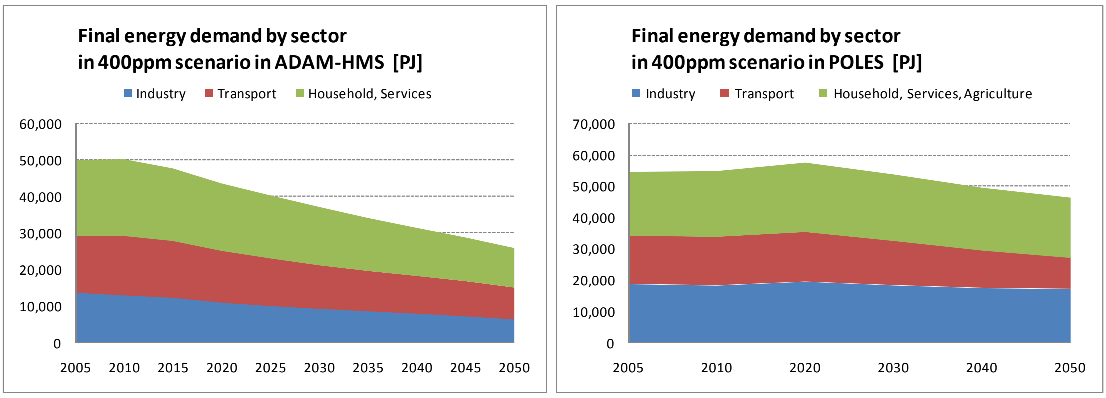


Figure 0-2: **Energy demand by sector of EU27 in ADAM-HMS and POLES (400 ppm scenario)**

Looking at the more detailed developments of energy demand in Table 0-1, it can be observed that, in the ADAM-HMS, the sectoral energy demand is reduced by -48 % in 2050 compared with 2010, while in POLES, the reduction amounts to only -15 %. The sectoral structure of reductions differs significantly. The total reductions are closest for the transport sector (-47 % and -36 %), while they differ significantly for industry and household/services, which cut demand by about half until 2050 in the ADAM-HMS, but by less than -10 % in POLES.

Table 0-1: Development of final energy demand in ADAM-HMS and POLES (400 ppm scenario)

	ADAM-HMS					POLES				
	Average annual change				Total change	Average annual change				Total change
	20 to 05	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**	**20 to 05**	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**
Industry	-1.4%	-1.6%	-1.8%	-1.7%	**-50%**	0.3%	-0.6%	-0.3%	-0.2%	**-6%**
Transport	-0.7%	-1.8%	-1.6%	-1.6%	**-47%**	0.2%	-1.1%	-1.8%	-1.1%	**-36%**
Household, services, agriculture	-0.8%	-1.4%	-1.9%	-1.6%	**-49%**	0.6%	-0.4%	-0.5%	-0.2%	**-8%**
Total	-0.9%	-1.6%	-1.8%	-1.6%	**-48%**	0.4%	-0.7%	-0.7%	-0.4%	**-15%**

Source: ADAM-HMS and POLES

Figure 0-3 presents the path for the CO_2 emissions in EU27 by sector for the ADAM-HMS and the POLES model. Reductions start around 2010 in both ADAM-HMS and POLES, although the reductions in POLES until 2020 are moderate compared with the ADAM-HMS calculations that reflect the immediate actions to reduce energy demand described above. A difference exists concerning energy conversion, for which negative CO_2 emissions occur in POLES in 2050 due to CCS, while in the ADAM-HMS CCS is not applied to energy conversion at all.

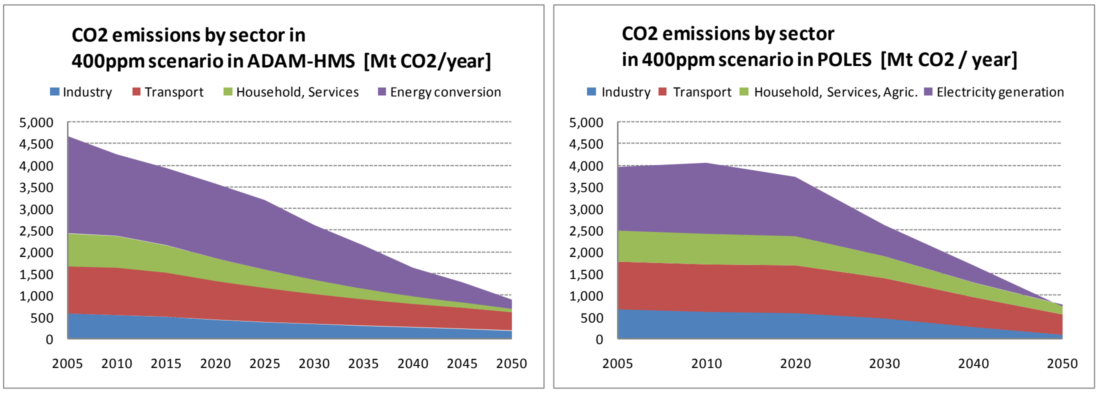


Figure 0-3: CO_2 emissions by sector of EU27 in ADAM-HMS and POLES (400 ppm scenario)

Looking at the sectoral details of CO_2 reductions in Table 0-2, it is once again clear that the results are closest for the transport sector, with a CO_2 reduction of -62 % by 2050 compared with 2010 in the ADAM-HMS and -58 % in the POLES model. For the industry sector, the POLES model calculates a more ambitious reduction path, while for household/services, the ADAM-HMS estimates the largest reduction of all final energy sectors with -88 % CO_2. For energy conversion/electricity generation, the diffusion of CCS technologies results in a stronger reduction in the POLES model amounting to -103 %, which means that CO_2 is removed from the atmospheric CO_2 cycle and stored underground due to the use of CCS and biomass in electricity generation.

Table 0-2: Development of CO_2 emissions in ADAM-HMS and POLES (400 ppm scenario)

	ADAM-HMS					POLES				
	Average annual change				Total change	Average annual change				Total change
	20 to 05	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**	**20 to 05**	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**
Industry	-1.9%	-2.4%	-2.9%	-2.6%	-65%	-0.9%	-2.2%	-7.4%	-4.4%	-84%
Transport	-1.3%	-2.6%	-2.4%	-2.4%	-62%	0.0%	-1.7%	-3.4%	-2.1%	-58%
Household, services, agriculture	-2.4%	-4.5%	-6.3%	-5.1%	-88%	-0.4%	-2.9%	-4.0%	-2.8%	-69%
Energy conversion / elec. Generation	-1.8%	-3.0%	-8.5%	-5.3%	-89%	-0.5%	-4.9%	~ -28%	~ -16%	-103%
Total	-1.8%	-3.0%	-5.1%	-3.8%	-78%	-0.4%	-3.1%	-6.0%	-4.0%	-81%

Source: ADAM-HMS and POLES

The broad message of the sectoral analyses performed for Europe using the ADAM-HMS and the POLES models is consistent: A pathway to reach the 2°C target is technologically feasible. However, there is no silver bullet in climate policies; many or even all the options of emission reductions will have to be energetically activated and sustained over a longer horizon. However, the two parallel approaches tell **two different storylines of how to achieve the 2°C target in Europe**: The baseline for both storylines is that carbon, or GHG emissions, has to be given a price, either in the form of an ETS or a greenhouse gas tax. However, such a policy on its own does not seem to be sufficient since (1) the price signals of an ETS in the first decades would be far too low to stimulate sufficient policy support for new technologies and sufficient behavioural change to implement sectoral policies, and (2) pricing systems are intended to affect markets, but markets in general apply a short-term perspective, looking at short-term rates of return and short-term break-even points, while the system transitions necessary for climate policy require a long-term perspective and can only be implemented over a long time horizon. Thus putting a price on greenhouse gases has to be accompanied by sectoral policies that give a powerful stimulus to new technologies and behavioural change from now until 2050.

The first storyline relates to the results of the ADAM-HMS. It concludes that the 2°C- Scenario for Europe can be achieved by: (1) immediate action investing in: (2) energy efficiency, (3) renewables, and (4) material efficiency. In case of partial failure to deliver or in case of delays, the second storyline from POLES could be followed, which argues that Europe can achieve the 2°C Scenario by (1) increased electrification, (2) high use of biomass (also from imports), and (3) substantial use of carbon capture and storage technologies (CCS). However, it should be mentioned that CCS constitutes only a transition technology because CO_2 storage capacities are finite and limit CCS in the long run.

Macro-economic analysis

The basic conclusion from an economic point of view is that mitigation measures needed to meet the 2-degree target of the EU will not fundamentally alter Europe's economic development path. Some European regions will actually be better off with mitigation than without mitigation. A loss of GDP in EU27 of -1.7% and -2.7% in the 450 ppm and 400 ppm variants of the 2°C Scenario respectively at the end of the period in 2050, is acceptable considering that the financial crisis caused losses of GDP of -4% to -6% in the EU27 within less than 2 years, while the impact of mitigation remains less than half of this over a period of 40 years.

The impact on employment remains even more limited than on GDP. It is projected to be between +0.2%, i.e. mitigation fosters employment growth, and -0.3% of employment change until 2050 for the different regions of the EU. However, the sectors display considerable variation. Agriculture and industry gain employment because of the increased use of biomass and the mitigation investment into all kinds of machinery and electric appliances. The energy sector and other market services loose in employment: energy because of the reduced demand for energy and the service sector because of the price increase of services induced by the mitigation investment of the service sectors. It should be noticed that the service sectors face significantly higher price increases due to mitigation investment than the manufacturing sectors.

Comparing the cumulative amount of mitigation investment and savings of fossil energy imports it can be observed that before 2040 the cumulative mitigation investments are significantly higher, but this is turned around by 2050 when the cumulative savings of energy imports become higher than the mitigation investment. This trend should continue after 2050 and in this sense, mitigation measures represent a pre-investment into a profitable future which constitutes a strong argument for mitigation in Europe, as it contributes to both the two major objectives of the EU: winning the battle against climate change and securing Europe's energy supply.

Impact of the current economic crisis on climate policy

The collapse of the global investment banks, with the consequent reduction in lending, instability of prices and falls in investment and trade, has led to reductions in industrial output, personal incomes, household expenditures, and hence in energy use and in greenhouse gas emissions. Since there is a data lag in the reporting of emissions, it is not yet clear how large the reduction will be, but it is likely to undermine earlier scenarios of continuous increases in emissions assumed in IPCC reports and other scenarios. Thus we applied a global energy-environment-economy model (E3MG) to assess these effects and find that the long-term effect of the crisis is to reduce CO_2 emissions by some 10% below a trend baseline by 2020. However, the recession is just beginning and it is far from clear how governments will react in their policies towards the energy sector, and whether the old coal-burning plant will be retired never to return.

In parallel to the macroeconomic analysis of the crisis, we checked our sectoral results in relationship with the potential impacts of the economic crisis on the sectors. The basic conclusion for Europe is that it will reduce the GHG emissions in the short-term and under a scenario of a permanent loss of GDP of -10% also in the long-term. The sectors reducing GHG emissions most due to the crisis would be industry and transport, where reductions in GHG emissions of the same order of magnitude as GDP can be expected.

In some cases, the crisis itself as well as the economic stimulus programmes will contribute to permanent reductions of GHG emissions by accelerating retirement of vehicles or facilities when their capacity is not needed anymore due to the crisis as well as by funding the renewal of vehicle fleets.

However, for the 2-degree scenarios there is also the major risk that lack of funding due to the crisis (e.g. because of reduced government budget) and increased risk averseness of investors or households will hamper the implementation of measures required to achieve the GHG emission reductions. This means, if policy does not put particular emphasis on mitigation policy the “conventional” way of handling the crisis will significantly reduce the chance that such 2-degree scenarios can be achieved. Therefore, **policy has to aim for policy programmes that integrate mitigating the crisis and mitigating climate change.** One option to link climate mitigation policy and crisis managment would be to follow the idea of the “Green New Deal”, which is to always link the economic stimulus with the requirement to introduce green technologies and GHG lean processes.

Policy conclusions

The broad message of the sectoral analyses performed for Europe is: **a pathway to reach the 2°C target is technologically feasible and economically viable.** However, there is no silver bullet in climate policies to achieve the goal and to optimize costs and benefits. All the options of emission reductions will have to be forcefully activated and sustained over a long time horizon. **A broad package of policies to stimulate technological change as well as behavioural change has to be implemented by the EU, the Member States, municipal governments and numerous actors from the public and the private sectors.** Most relevant measures are:

- Assigning carbon (or GHGs) a price is a major pre-requisite for successful climate policy, as it translates environmental constraint into a market signal. However, this is only a necessary pre-requisite, not a sufficient stand-alone instrument to achieve the 400 ppm targets.
- Implement a coherent set of policy measures such to overcome barriers that prevent investments in cost-effective and low-cost energy-efficiency measures and renewable energies: codes and standards including MEPS, preferential loans and other financial instruments, labels and other information measures. Temporarily limited subsidy schemes that could be financed by a carbon levy might be necessary to achieve fast diffusion of new technologies.
- New technologies play a very important role in achieving the goals of ambitious climate policy. Thus massive investments for public and private R&D are required for efficiency technologies (e.g. in buildings, vehicles, industrial processes), renewables and, to limited extent, also CCS.
- The take-up of low carbon technologies by the markets has to be accelerated. This should be achieved by norms, standards and labels wherever appropriate, e.g. in buildings, vehicles or power plants. The second effect of norms and standards is that they provide certainty for investors who plan for investments requiring a long-term payback period.
- Take immediate action since each year lost before shifting the transition pathway towards a low carbon society represents a year requiring even stronger action in the subsequent years.

The measures suggested in this report are not science fiction. However, they need strong support by todays policy-makers, who have the most difficult task. They will have to promote such policies even though visible climate impacts are limited, yet, and knowledge of the possible impacts is limited as well. Future generations of policy-makers - and private decision-makers - will have an easier task, as climate change will be more visible. On the other hand, for future policy-makers it would be too late to mitigate climate change, if todays policy-makers do not start to implement our suggested mitigation measures.

1 Introduction

Authors: Wolfgang Schade, Eberhard Jochem

The ADAM project is funded by the European Commission to research strategies for mitigating and adapting to climate change from a European perspective but in a global context. The research was conducted between March 2006 and July 2009 by a Consortium of 24 European research institutes, together with one partner from each of China and India. The Consortium is led by the Tyndall Centre for Climate Change Research at the University of East Anglia, UK.

ADAM research identifies and appraises existing and new policy options that would be able to contribute to different combinations of adaptation and mitigation strategies. These options address the demands a changing climate will place on protecting citizens and valuable ecosystems – i.e., **adaptation** – as well as addressing the necessity to restrain/control humankind's perturbation to global climate to a desirable level – i.e., **mitigation**. The focus of this deliverable is on technological options for mitigation in Europe. This includes the analysis of new technologies and their diffusion into the market. This is completed by an analysis of the policy instruments fostering new technologies and other mitigation measures.

The ADAM work programme is structured around four overarching domains: Scenarios, Adaptation, Mitigation and Policy Appraisal. In addition, four Case Studies were completed in which synergies and tradeoffs between climate change mitigation and adaptation strategies were analysed at different scales, at the European and the global level. **The work presented in this deliverable belongs to the mitigation domain of ADAM**. The deliverable deals with two parallel analytic approaches to develop mitigation scenarios for Europe that would put the EU27 on a path towards a 2-degree world. The two parallel approaches are using (1) the ADAM Hybrid Model System (ADAM-HMS), and (2) the POLES world energy system model. The focus of the deliverable is on the results of the ADAM-HMS, which are contrasted and compared with the results of the POLES model. The analysis is undertaken as part of the work package Mitigation M1 led by Fraunhofer-ISI collaborating with a core group of partners including Paul Scherrer Institute (PSI), Centre for Energy Policy and Economics at ETH Zurich (CEPE), BSR Sustainability GmbH (BSR), National Centre for Scientific Research, Energy and Environmental Policy at CNRS (LEPII) and Wageningen University (Alterra) supported by Potsdam Institute for Climate Impact Research (PIK), Enerdata and Cambridge University (UCAM).

1.1 Climate policy: past and future

At the United Nations Conference on Environment and Development in 1992 in Rio de Janeiro, Brazil – the so called Rio Earth Summit – the foundations of today's climate policy were laid by agreeing on the United Nations Framework Convention on Climate Change (UNFCCC). The Convention sets an ultimate objective of stabilizing greenhouse gas concentrations "*at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system.*" It states that "*such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner*." [UN 1992].

The Convention placed the heaviest burden for fighting climate change on industrialized nations, since they are the source of most past and current greenhouse gas emissions. These countries are asked to do the most to cut their greenhouse gas emissions, and to provide most of the money for efforts elsewhere. For the most part these industrialised nations belong to the Organization for Economic Cooperation and Development (OECD). In the terms of the UNFCCC they are called "Annex I" countries because they are listed in the first annex to the Convention. The European Union (EU) belongs to these Annex I countries, such that developing an appropriate mitigation strategy for the EU as attempted in this deliverable also contributes to the UNFCCC and its succeeding agreements.

1.1.1 Current international climate policy: Kyoto Protocol and EU-ETS

The major agreement that was put into force as a follow-up to the UNFCCC is the so-called Kyoto Protocol, which was adopted in Kyoto, Japan, on 11th December 1997 and entered into force on 16th February 2005. 184 Parties of the Convention have ratified its Protocol to date. The major distinction between the Protocol and the Convention is that while the Convention encouraged industrialised countries to stabilize GHG emissions, the Protocol commits them to do so [UN 1998].

In fact, the Kyoto Protocol sets binding targets for 37 industrialized countries and the European Union for reducing greenhouse gas (GHG) emissions. These reductions amount to an average of five per cent against 1990 levels over the five-year period 2008-2012. Countries with commitments under the Kyoto Protocol to limit or reduce greenhouse gas emissions must meet their targets primarily through national measures. As an additional means of meeting these targets, the Kyoto Protocol introduced three market-based mechanisms, thereby creating the so-called “carbon market.” The Kyoto mechanisms are:

- Emissions trading,
- clean development mechanism (CDM), and
- joint implementation (JI).

To participate in the Kyoto mechanisms, Annex I Parties of UNFCCC must meet, among others, a number of eligibility requirements. First, they must have ratified the Kyoto Protocol and must have calculated their assigned amount of greenhouse gas emissions (GHG) in terms of tonnes of CO2-equivalent emissions. A national system for estimating emissions and removals of greenhouse gases within their territory has to be put in place as well as a national registry to record and track the creation and movement of savings of GHG and their equivalent tradable emissions allowances. Finally, an annual reporting of emissions and removals has to be delivered to the UNFCCC.

The EU has committed itself under the Kyoto Protocol to achieve a reduction of -8% of GHG emissions for the period 2008 to 2012 compared with 1990. The EU Member States have agreed on a distribution of reductions amongst them defining individual reduction targets for each country. The major instrument to achieve these reductions was the initialisation of the EU Emissions Trading System (EU-ETS) commencing in 2005 and being agreed in 2003 by EU Directive 2003/87/EC [EU 2003]. The EU-ETS implemented the requirements of the Kyoto Protocol by setting a cap (i.e. a maximum quantity of allowed greenhouse gas emissions) for the large industrial emitters of GHGs and the energy conversion sector in the EU. However, sectors like transport, residential or services were mainly left outside the EU-ETS (i.e. besides indirect effects that feed back on these sectors from the EU-ETS sectors).

1.1.2 Future climate policy: Post-Kyoto developments

Since, the commitment period of the Kyoto Protocol ends in 2012 and there has been no follow-up agreement put into place, so far, there is currently no further binding **global** concrete climate policy agreement existing for the time period after 2012. However, the Intergovernmental Panel on Climate Change (IPCC) reported in its fourth assessment report that the signals of climate change have developed stronger than estimated in the previous assessment report and that there might only be a short window of opportunity during which it will still be feasible to limit climate change to a 2-degree Celsius temperature increase, only, compared with pre-industrial levels [IPCC 2007]. With a temperature increase of 2-degree Celsius it is assumed that negative consequences of climate change remain limited and no tipping points of the natural systems are reached.[1] Thus the term **2-degree target** is coined, expressing the target to reach a manageable level of climate change by mitigation measures.

Since the fourth IPCC assessment report in 2007 a number of observations indicate the risk of already accelerating changes in natural systems. Such observations make it even more relevant to continue the process under the UNFCCC and to develop a new global agreement for the Post-Kyoto period i.e. after 2012. An important step forwards, if not even a breakthrough, is expected to be achieved at the next conference of the parties (COP-15), which will be held in December 2009 in Copenhagen, Denmark. The EU has developed its position for COP-15 through a number of communications, which all emphasize the 2-degree target [e.g. EC 2007, EC 2009]. Basically, the European message is that the EU will reduce its GHG emissions be -20% until 2020 compared with 1990, even if the rest of the world would not agree on reductions. If a joint global agreement similar to the Kyoto-Protocol would be achieved for the Post-Kyoto period the EU would even accept a reduction target of -30% until 2020. On the global level the EU formulates the target of a reduction of -50% GHG emissions by 2050 compared with 1990, which according to IPCC means a reduction of -80 to -95% by the industrialised countries by 2050.

A path to achieve a -80% reduction also underlies the work in the work package Mitigation M1 described in this deliverable. It is obvious that this level of reductions can not be achieved by looking at the EU-ETS sectors only. The remaining sectors have to contribute to GHG emission reductions, such that the mitigation analysis in this work package considers the sectors households, industry, services, transport, renewables and energy conversion and puts a particular focus on energy efficiency and material efficiency in these sectors.

1.1.3 Related policy framework in the EU and Member States

Besides the introduction of the EU-ETS the European Union and its Member States have taken a number of policy measures that complement the EU-ETS and thus also contribute to mitigation of climate change. An important step forward was the so-called European Energy and Climate Package “20 20 by 2020” [EC 2008]. It confirmed the objective to reduce GHG emissions by 2020 by -20% unilaterally and brought forward the target to reach a level of 20% renewables for energy production by 2020 as well. The EU-ETS sectors should contribute a reduction of -21% by 2020 and for the first time also the Non-ETS sectors – e.g. transport, housing, agricul-

1 Recent evidence suggests that even with the restriction to 2-degree C temperature rise, climate impacts will be considerable [e.g. Heimann/Reichstein 2008].

ture and waste – were made subject to a GHG reduction target i.e. they should reduce their emissions by -10% by 2020 compared with 2005. Further the EC seeks to develop the Carbon Capture and Storage (CCS) technology.

Such an ambitious policy package gained momentum through a publication on behalf of the UK government, which was “The Economics of Climate Change”, the so-called Stern Review [HM Treasury 2006]. The Stern Review concluded that climate change, if not mitigated, could cost about 5-20% of global GDP, while the cost of mitigation would remain at the order of 1% of global GDP. This was a strong signal in favour of mitigation policy and thus a driver for the work in our work package M1.

The EU put another policy focus related to GHG reductions and energy security on energy saving and energy efficiency. It defined an indicative target that EU Member States should increase their energy efficiency and reduce their energy consumption by -9% until 2016 compared with 2006 [EU 2006]. Since GHG emissions are close to proportional to energy consumption this target would have a similar reduction effect on GHG emissions.

More specifically the EU tackled the CO2 intensity of passenger transport by introducing a binding legislation according to which the average of all new passenger cars sold in Europe in 2015 should emit not more than 130 g CO2/km such that considering the use of biofuels and further eco-innovations the binding target for the average new passenger car fleet in 2015 is set to 120 g CO2 / km, which means a reduction of -20 to -25% (depending on the country) compared with today [EU 2009].

On the level of the Member States similar policy programmes have been defined, both to implement the EU directives and regulations and to develop a national climate change mitigation approach. One example is the German Meseberger Integrated Energy and Climate Programme (IECP) [BMU 2007]. The IECP defines 29 policy measures / policy packages. It consists of a mix of energy efficiency improvement measures, which indirectly reduce GHGs as pointed out above, and direct GHG reduction measures. Examples, of the former are the energy efficient rehabilitation of houses or energy efficiency measures in businesses (e.g. direct via energy management and indirect via efficiency standards of appliances). Examples of the latter are renewables policies for electricity and heating (e.g. feed-in tariffs) or a package to reduce CO2 emission from passenger cars including CO2 emission limits, CO2 based taxation and CO2 efficiency labelling.

The policy framework developed by the EU and the Member States can be summarised by the following broad options of climate mitigation policy:

- Introduce GHG emissions trading,
- Increase of energy efficiency,
- Focus on renewable energies,
- Setting standards and norms that drive technological development, and
- Include all sectors and all greenhouse gases in the mitigation efforts.

This framework is followed in the analysis throughout this deliverable: our assessment is that it would provide a suitable framework to reduce drastically the GHG emissions in Europe by 2050.

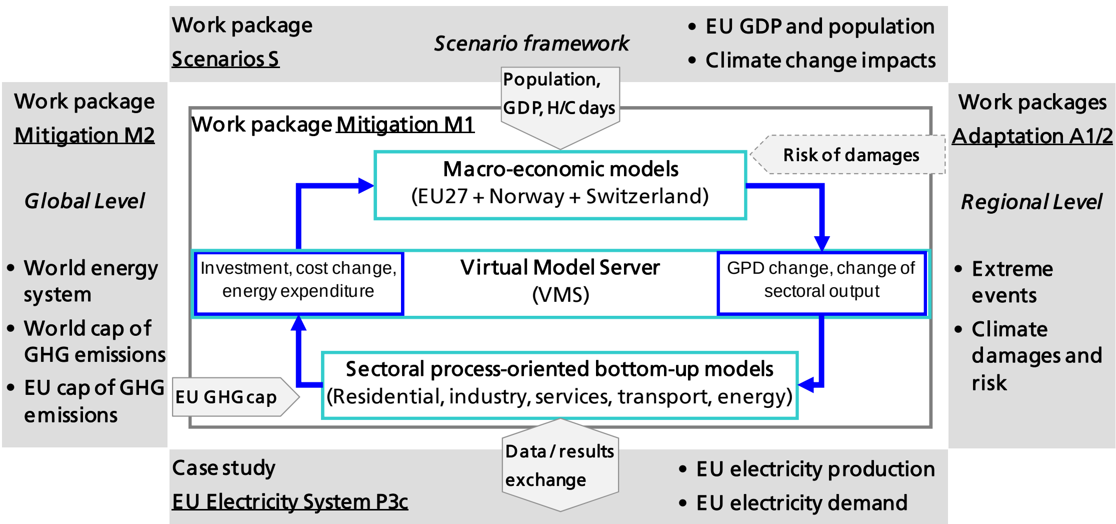
1.2 Approach of work package Mitigation M1

Our work package Mitigation 1 (M1) has the **core objective to simulate mitigation options and their related costs for Europe until 2050 and 2100 respectively**. **The focus of this deliverable is on the period 2005 to 2050.** The longer-term period until 2100 is covered in the previous deliverable D-M1.2, applying the POLES model for this time horizon [Eberhard et al. 2009].

Our analysis in work package M1 constitutes basically a techno-economic analysis. Depending on the sector analysed it is either directly combined with a policy analysis (e.g. in the transport sector, renewables sector) or the policy analysis is performed qualitatively as a subsequent and independent step after the techno-economic analysis is completed (e.g. in the residential and service sectors).

Figure 1-1 presents the embedding of work package M1 into the broader frame of the ADAM project. As Europe obviously forms part of global emission reduction activities, the analysis of M1 also depends on the economic and policy assumptions as well as the results of work package Mitigation M2 (covering the global level), on the results of work package Scenarios S (providing a common framework of scenarios in the ADAM project) and on work packages Adaptation A1 and A2 (assessing the risks and damages of climate change). These ADAM work packages provide inputs to our work in work package M1 in the form of scenario inputs (e.g. GDP, population projections, heating and cooling days) and model results (e.g. European CO2 emission pathway to reach 2-degree considering the global context, consequences of adaptation).

The broad relationships between these work packages and inbetween of our work package M1 is shown in Figure 1-1. Within M1 there is interaction between macro-economic models and sectoral process oriented bottom-up models, which communicate recursively with each other via the Virtual Model Server (VMS), a tool enabling and structuring the data transfer between models. This hybrid model system (HMS) of M1 is fed by the harmonised socio-economic ADAM storylines from the work package Scenarios S. Further work package S provided the changes of heating and cooling days (H/C days) for the EU Member States. The world reference scenario of the energy system and the global GHG emissions is provided by the work package M2 applying the POLES, REMIND and IMAGE models and delivering a European GHG emissions pathway for the mitigation scenarios to M1, which is input to the bottom-up models of M1. The adaptation work packages provide specific inputs either to the economic models or the bottom-up models of our work package M1 e.g. potential damages to the capital stock. However, the latter interaction remained limited. Finally, there has been exchange of data and results with the case study on the European electricity system (P3c).



Source: ADAM-M1

Figure 1-1: Overview of the model system of WP Mitigation M1 and its context of related ADAM work packages Mitigation M2, Adaptation A1 and A2, Scenarios S

There are *four major methodological challenges* in work package M1:

- The integration of the economic and technical developments in Europe into global development. This is handled by linking work package M1 with the global mitigation work package M2 and using the model results from their models, in particular POLES, E3MG and REMIND.

- The differences in economic and technical development within Europe with the presently quite different conditions of the capital stock and the economic performance in Western, Southern, and Eastern Member States of the European Union.
- The differences in natural resources (such as potentials of renewable or fossil energies, climate conditions), which suggest different mitigation and adaptation policies in the various European Member States.
- Finally, the integration of 10 models applied in work package M1 to generate the results on different structural levels, i.e. eight models provide results on the bottom-up level that is considering sectoral technologies and processes to implement these technologies, while two models handle the macro-economic and global level, respectively.

This report is the third in a sequence, which started with deliverable D1 on the *Base Case Scenario* without climate change and also provided the model descriptions [Eberhard et al. 2007] followed by deliverable D2 on the impact of adaptation of the energy system in the *Reference Scenario* and a meso-level analysis of a 2-degree scenario until 2100 [Eberhard et al. 2009]. This final report describes two detailed variants of a *2-degree Mitigation Scenario* for Europe to 2050 and compares them with the Reference Scenario.

1.3 Issues of mitigation analysis in Europe

Economic and technical developments and climate change in Europe are part of the global economic and technical developments and their related greenhouse gas emissions. In order to design possible future adaptation and mitigation scenarios, therefore, a global context has to be taken into account. This is achieved by the ADAM work package Scenarios where climate change is simulated based on projected global emissions and by work package Mitigation 2, where the techno-economic development of the rest of the world and the associated greenhouse gas emissions are calculated for the period 2000 to 2100, and by the global POLES eneryg system model that is also part of work package M1.

The European countries are presently at different stages of their techno-economic development. Whereas some countries have almost fully complete infrastructures, few basic industries, and more than two thirds of their GDP generated by services (e.g. Switzerland, Denmark, Sweden), some of the Central European countries have relatively poor infrastructures, low incomes per capita, a relatively high share of GDP generated by agriculture, and a low degree of motorisation and automation.

Because of the different population densities, landscape and climates, European countries have different potentials to use renewables (e.g. photovoltaics, wind energy) or biomass e.g. wood production per capita or additional felling potentials in the next decades which offer opportunities for reducing energy-related greenhouse gases by using more wood as a fuel or by using forests as carbon stores or in long-lasting wood uses (e.g. houses and buildings).

Macroeconomic models have an advantage in simulating the cycles of goods and money, but they are not able to simulate new technological developments in detail. On the other hand, *sectoral, process-oriented bottom*-up *models* that can simulate technical and organisational innovations cannot adequately simulate the indirect cost of the energy system on the national economy or on foreign trade patterns. This dilemma can be solved by hybrid model systems (HMS) consisting of macroeconomic and bottom-up models which exchange the results between them. Such a system is developed in this work package Mitigation M1. We call it the ADAM-HMS. The system is then applied to develop mitigation strategies for Europe until 2050.

1.4 Objectives and scenarios of this deliverable

This deliverable presents the final results of work package M1 on “Mitigation for Europe”. It provides results of two variants of a possible 2-degree scenario with target concentrations of CO2 of 450ppm (the so-called **450ppm scenario**) and of 400ppm (the so-called **400ppm scenario**). These two scenario variants are compared with the **Reference Scenario**, which is described in detail in the deliverable D2 of work package M1. This reference scenario has been slightly improved for this deliverable, such that where necessary updated results of the reference scenario are reported and are used for the comparison of the 2-degree scenarios with the reference scenario.

The work on “Mitigation for Europe” is embedded into the larger framework of the ADAM project, in which also the “Mitigation on Global Level” is analysed in work package M2 of ADAM. The global analysis provided a pathway of allowed GHG emissions of Europe for our work taking into account the mitigation activities on global level and thus providing guidance on the efforts Europe has to contribute. This GHG pathway was used as benchmark into which the aggregate sectoral GHG emissions in our work have to fit.

The **first objective of this deliverable** is then to analyse technological options as well as potential policies in all relevant sectors to reduce GHG emissions of these sectors such that the aggregate GHG emissions of all sectors follow the required European GHG pathway in a 2-degree scenario. The themes considered in detail are:

- Forestry and energy crops,
- material use and material efficiency in industry,
- basic products and industrial sector,
- services sector,
- residential sector,
- transport sector, and the
- power generation from renewable energies and energy conversion sector.

For each theme a model-based techno-economic bottom-up analysis of technological options, diffusion of technologies, cost of diffusion, potential and required policies for technology diffusion is undertaken. The cost and investment results on the sectoral level are then transferred into a macro-economic model, which calculates the impacts of the bottom-up technology diffusion and policies on the economy, in particular on growth and employment. Thus the **second objective of this deliverable** is to analyze the economic impacts of a mitigation policy in Europe that would bring Europe onto a globally aligned 2-degree development path until 2050.

1.5 Structure of this deliverable

This deliverable is structured in four main sections. The first section presents the framework and the methodological approach of our work. It consists of the executive summary, the introduction, the description of the framework conditions and the methodology.

The second main section describes the bottom-up analysis consisting of the two parallel streams of analysis based (1) on the ADAM hybrid model system (HMS) consisting of 9 sectoral and separate bottom-up models, and (2) on the POLES model. It starts with the POLES model as this also provides inputs to the ADAM-HMS followed by seven sections on the sectoral bottom-up models (forest and material efficiency, residential, services, industry, transport, renewables and conversion sector), and concludes with a synthesis of the bottom-up analysis.

The third main section describes the macro-economic consequences for Europe. It consists of two sections: one on the economic impacts of EU climate policy to 2050 and another one on the potential impacts of the economic crisis on climate policy to 2020. The final section presents the analytic and policy conclusions of our analyses.

2 Scenarios and macroeconomic assumptions

Author: Wolfgang Schade

This section presents the economic, demographic and energy prices scenario of the analysis in the work package Mitigation M1. The broad framework i.e. the scenario input on country level is provided by the ADAM work package Scenarios. The framework is then implemented into the macro-economic models (i.e. ASTRA and E3MG), which then disaggregate the input e.g. onto the level of economic sectors by country and then deliver the sectoral input for the bottom-up analysis (see section 3 on methodology).

The following sections present the general assumptions divided into the three sections: scenario set-up, economic and demographic trends as well as trends of energy prices.

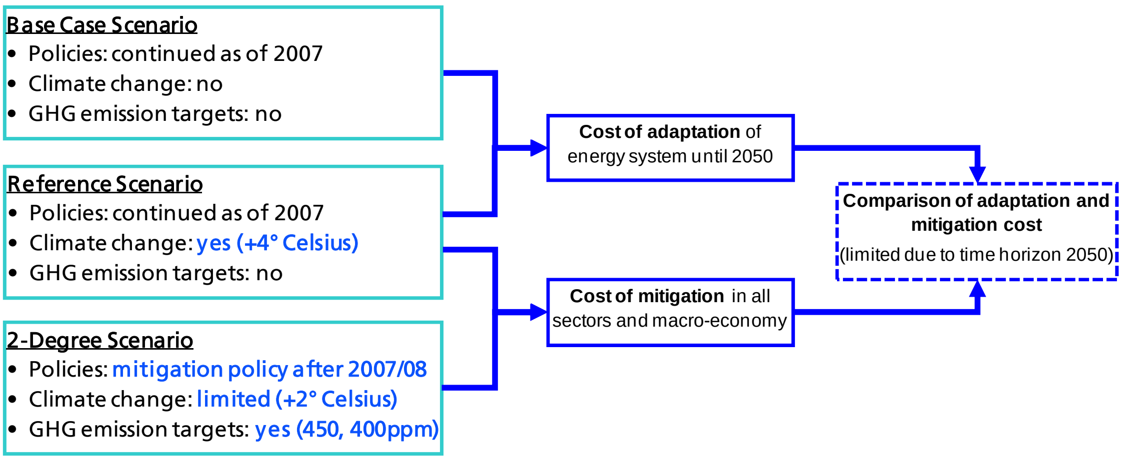
2.1 Definition of Scenarios

In the course of the work on work package M1 three scenarios have been developed of which one scenario is developed in two variants. Figure 2-1 presents an overview on these scenarios and their main differences. The **Base Case Scenario** provides a virtual scenario, in which the policies are continued as defined in the year 2007. There are no GHG emission targets defined for the longer term i.e. for the years 2020 and 2050 (the Kyoto targets for 2008 to 2012 existed already in the year 2007) and climate change i.e. temperature increase does not occur, which makes it a virtual scenario as with increasing emissions we would have climate change. This scenario was used to establish the links between the models and to achieve a common and consistent reference.

The **Reference Scenario** differs from the Base Case Scenario by the fact that climate change is actually occurring i.e. the world is facing an increase of temperature by +4-degree Celsius by 2100 compared with pre-industrial levels. In other ADAM work packages this scenario is named Adaptation Scenario, which was avoided in M1 as most of adaptation (in particular the more severe damages and the sea level rise) would occur after 2050 i.e. outside the time horizon of this deliverable. Thus the purpose of the Reference Scenario is twofold (1) to provide a realistic scenario for the comparison with the following 2-Degree Scenario (i.e. mitigation scenarios), and (2) to provide an assessment of the adaptation cost of the energy system, which will react earlier than other systems (e.g. by using more air-conditioning in buildings and vehicles or by requiring more or differently equipped power-plants in summer to cope with the reduced cooling capacity of rivers) in response to continuously increasing temperatures.

The **2-Degree Scenario** is developed in two variants reflecting the uncertainty about with which level of $CO2_{eq.}$ concentrations the increase of temperature can actually be limited to 2-degree Celsius until 2100. The two variants represent (1) a concentration of 450 ppm $CO2_{eq.}$ in the long run and (2) a concentration of 400ppm $CO2_{eq.}$ of which the former would provide a 50% likelihood that the 2°C target is achieved and the latter a 70% likelihood. In the 2-Degree Scenarios after 2008 mitigation policies are implemented and climate change is successfully limited to +2°C, such that adaptation impacts to climate change remain very limited. The comparison between the Reference Scenario and the 2-Degree Scenarios reveals the cost (or benefit) of mitigation policy. Thus the 2-Degree Scenarios represent a mitigation scenario.

One could also compare the adaptation cost and the mitigation cost derived from the scenario comparisons. However, making this comparison one must have in mind that the bulk of mitigation actions and the related cost occur before 2050, while for adaptation it is vice versa i.e. the bulk of adaptation cost, in particular damage cost, health cost or cost of sea level rise will only occur after 2050. Thus such a comparison would naturally be skewed, unless, the different time horizons for which adaptation impacts and mitigation measures have to be considered were taken into account.



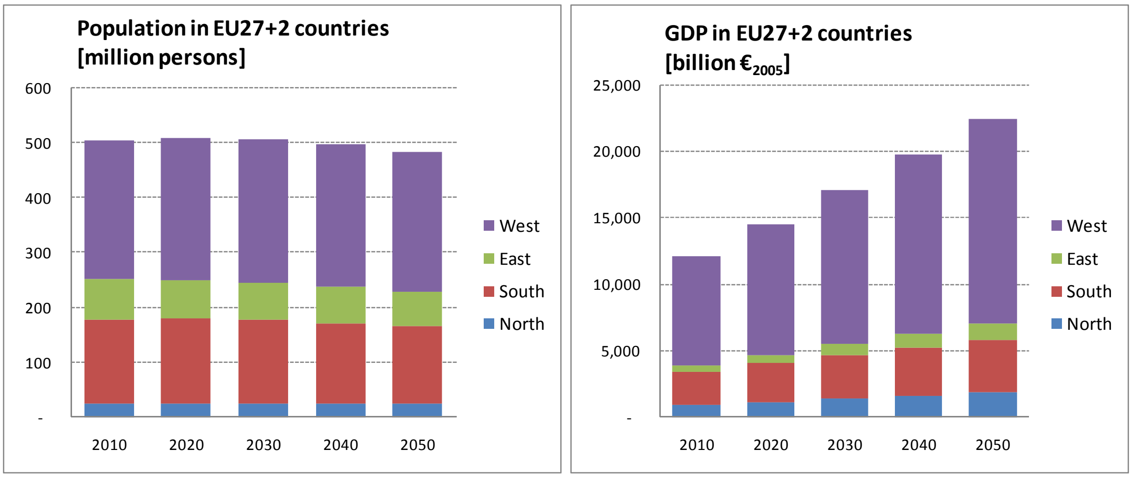
Source: ADAM-M1.

Figure 2-1: Definition of scenarios and purpose of scenario comparison

2.2 Demographic and economic conditions

Work package Scenarios S provides a common scenario for population and GDP for the European countries. In work package M1 sone of the models that are applied endogenously calculate these two indicators by themselves (e.g. ASTRA model). The endogenous trends of these indicators have been adjusted in the ASTRA model to fit the common scenario framework as closely as possible to. Since the ASTRA model forwards its results to the sectoral bottom-up models the ASTRA trends are presented in the following Figure 2-2. Population in EU27+2 grows until 2020 and then starts to decline leading to a reduction of -4% by 2050 compared with 2010.[2] However, the situation differs between the regions. The Southern and Eastern EU countries loose about -10% of population, while the Northern countries increase by about +5% and the Western countries remain nearly stable.

In terms of GDP the situation differs. The EU27+2 grow by about +85% between 2010 and 2050 (in real terms). The strongest growth is expected for the Eastern countries (about +170%) followed by the Northern and Western countries (around +90%). The Southern countries loose ground with a slower growth of about +60%. In particular, this means that the catch-up process in the Eastern countries will continue until at least 2050.



Source: ASTRA model reflecting the ADAM scenario framework.

Figure 2-2: Population and GDP framework in the Reference Scenario

2 The population projections allow for a net inwards migration into the EU between 1.3 and 1.4 million persons annually.

The following Table 2-1 and Table 2-2 present the population and GDP development until 2050 country-by-country, respectively. It should be noted that EU27 refers only to the EU Member States (i.e. excluding Norway and Switzerland), while the region North includes Norway and West includes Switzerland in the tables.

Table 2-1: Population development in EU27+2 countries until 2050 (all scenarios)

	All Scenarios [Mio persons]					Changes (average annual population change [%])				
Country or country group	**2010**	**2020**	**2030**	**2040**	**2050**	**'20 to '10**	**'30 to '20**	**'40 to '30**	**'50 to '40**	**'50 to '10**
Austria	8.3	8.4	8.5	8.4	8.2	0.2%	0.1%	-0.1%	-0.2%	0.0%
Baltic States	6.9	6.6	6.3	6.1	5.9	-0.5%	-0.4%	-0.3%	-0.4%	-0.4%
Belgium/Lux.	11.0	11.3	11.5	11.6	11.6	0.3%	0.2%	0.1%	0.0%	0.1%
Bulgaria	7.4	6.8	6.2	5.6	5.1	-0.8%	-0.9%	-1.0%	-0.9%	-0.9%
Czech Republic	10.1	10.0	9.7	9.3	8.9	-0.1%	-0.3%	-0.4%	-0.4%	-0.3%
Denmark	5.5	5.5	5.5	5.5	5.4	0.1%	0.0%	0.0%	-0.2%	0.0%
Finland	5.3	5.4	5.4	5.4	5.2	0.2%	0.1%	-0.1%	-0.2%	0.0%
France	61.5	63.4	65.0	65.8	65.9	0.3%	0.2%	0.1%	0.0%	0.2%
Germany	82.7	82.4	81.1	78.6	74.7	0.0%	-0.2%	-0.3%	-0.5%	-0.3%
Greece	11.2	11.4	11.3	11.1	10.6	0.2%	-0.1%	-0.2%	-0.4%	-0.1%
Hungary	10.0	9.7	9.5	9.2	8.9	-0.2%	-0.3%	-0.3%	-0.3%	-0.3%
Ireland	4.3	4.8	5.1	5.3	5.5	0.9%	0.6%	0.4%	0.3%	0.6%
Italy	58.5	58.4	57.1	55.3	52.8	0.0%	-0.2%	-0.3%	-0.5%	-0.3%
Malta/Cyprus	1.2	1.3	1.4	1.5	1.5	0.9%	0.6%	0.4%	0.2%	0.5%
Netherlands	16.7	17.2	17.5	17.6	17.4	0.3%	0.2%	0.1%	-0.1%	0.1%
Norway	4.7	4.8	4.9	5.0	5.0	0.2%	0.3%	0.2%	0.0%	0.2%
Poland	37.9	37.2	36.4	35.0	33.6	-0.2%	-0.2%	-0.4%	-0.4%	-0.3%
Portugal	10.7	10.8	10.7	10.4	10.0	0.1%	-0.1%	-0.2%	-0.4%	-0.2%
Romania	21.4	20.4	19.3	18.2	17.0	-0.5%	-0.5%	-0.6%	-0.7%	-0.6%
Slovakia	5.3	5.3	5.2	5.0	4.7	-0.1%	-0.2%	-0.4%	-0.5%	-0.3%
Slovenia	2.0	2.0	2.0	2.0	1.9	0.0%	-0.1%	-0.2%	-0.3%	-0.1%
Spain	44.4	45.7	45.5	44.6	42.7	0.3%	0.0%	-0.2%	-0.4%	-0.1%
Sweden	9.2	9.6	9.9	10.1	10.2	0.4%	0.3%	0.2%	0.1%	0.3%
Switzerland	7.5	7.5	7.3	7.1	6.7	0.0%	-0.2%	-0.4%	-0.5%	-0.3%
United Kingdom	61.0	62.8	64.2	64.8	64.4	0.3%	0.2%	0.1%	-0.1%	0.1%
EU27	**492**	**496**	**494**	**486**	**472**	**0.1%**	**0.0%**	**-0.2%**	**-0.3%**	**-0.1%**
North	25	25	26	26	26	0.3%	0.2%	0.1%	0.0%	0.1%
South	155	155	152	147	140	0.0%	-0.2%	-0.3%	-0.5%	-0.3%
East	72	71	69	67	64	-0.2%	-0.3%	-0.4%	-0.4%	-0.3%
West	253	258	260	259	254	0.2%	0.1%	0.0%	-0.2%	0.0%

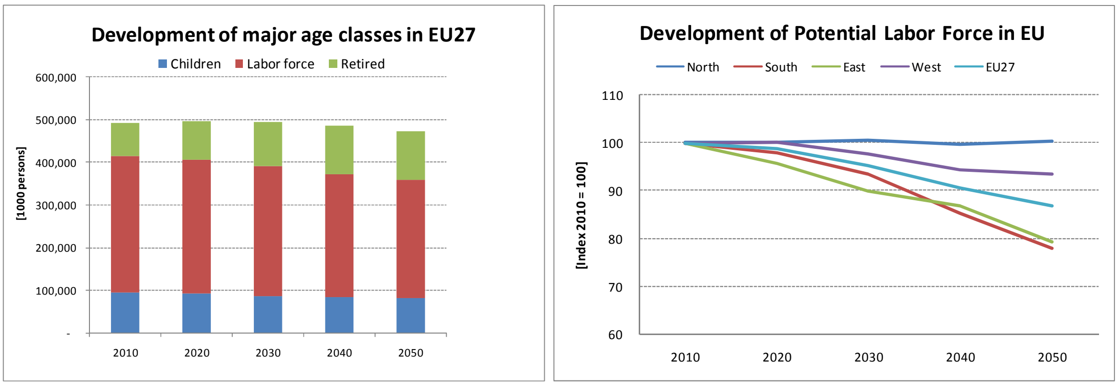
Source: Fraunhofer-ISI, ASTRA model in ADAM-M1.

Table 2-2: GDP development in EU27+2 countries until 2050 (Reference Scenario)

Country or country group	Reference Scenario [Billion €$_{2005}$]					Changes (average annual GDP growth [%])				
	2010	2020	2030	2040	2050	'20 to '10	'30 to '20	'40 to '30	'50 to '40	'50 to '10
Austria	289	339	384	424	467	1.6%	1.2%	1.0%	1.0%	1.2%
Baltic States	30	39	50	62	75	2.7%	2.5%	2.2%	1.8%	2.3%
Belgium/Lux.	363	407	452	496	539	1.2%	1.0%	0.9%	0.8%	1.0%
Bulgaria	17	22	27	31	34	2.2%	2.2%	1.6%	0.9%	1.7%
Czech Republic	73	89	110	128	144	2.1%	2.1%	1.6%	1.1%	1.7%
Denmark	216	265	316	364	416	2.1%	1.8%	1.4%	1.3%	1.7%
Finland	195	230	263	290	316	1.7%	1.3%	1.0%	0.9%	1.2%
France	1,947	2,369	2,935	3,654	4,476	2.0%	2.2%	2.2%	2.1%	2.1%
Germany	3,015	3,602	4,063	4,453	4,781	1.8%	1.2%	0.9%	0.7%	1.2%
Greece	163	169	187	219	269	0.3%	1.1%	1.6%	2.1%	1.3%
Hungary	64	81	97	111	124	2.3%	1.9%	1.4%	1.1%	1.7%
Ireland	111	132	149	159	160	1.7%	1.2%	0.7%	0.0%	0.9%
Italy	1,317	1,484	1,644	1,768	1,880	1.2%	1.0%	0.7%	0.6%	0.9%
Malta/Cyprus	18	21	24	28	31	1.6%	1.7%	1.3%	1.1%	1.4%
Netherlands	543	653	803	962	1,109	1.9%	2.1%	1.8%	1.4%	1.8%
Norway	221	287	351	423	520	2.6%	2.0%	1.9%	2.1%	2.2%
Poland	232	346	475	629	746	4.1%	3.2%	2.8%	1.7%	3.0%
Portugal	160	201	239	273	313	2.3%	1.8%	1.3%	1.4%	1.7%
Romania	39	49	61	74	83	2.2%	2.3%	1.9%	1.2%	1.9%
Slovakia	28	37	47	61	74	2.9%	2.5%	2.6%	1.9%	2.5%
Slovenia	36	47	58	69	78	2.8%	2.1%	1.7%	1.3%	2.0%
Spain	784	929	1,075	1,207	1,359	1.7%	1.5%	1.2%	1.2%	1.4%
Sweden	341	404	484	562	633	1.7%	1.8%	1.5%	1.2%	1.6%
Switzerland	386	466	536	591	635	1.9%	1.4%	1.0%	0.7%	1.2%
United Kingdom	1,503	1,835	2,230	2,679	3,152	2.0%	2.0%	1.9%	1.6%	1.9%
EU27	**11,483**	**13,750**	**16,174**	**18,704**	**21,260**	**1.8%**	**1.6%**	**1.5%**	**1.3%**	**1.6%**
North	972	1,186	1,414	1,639	1,885	2.0%	1.8%	1.5%	1.4%	1.7%
South	2,499	2,873	3,258	3,600	3,971	1.4%	1.3%	1.0%	1.0%	1.2%
East	462	640	838	1,061	1,240	3.3%	2.7%	2.4%	1.6%	2.5%
West	8,157	9,804	11,551	13,418	15,318	1.9%	1.7%	1.5%	1.3%	1.6%

Source: Fraunhofer-ISI, ASTRA model in ADAM-M1.

Particular attention should be paid to the changing demographic structure and the implications for employment. Figure 2-3 presents on the left hand side the age composition of the EU27 population. It can be observed that the number of children and the potential labor force reduces until 2050, while the number of retired persons is increasing. These numbers are calculated with children being persons that are 18 years old or younger and retired being persons that are 65 years old or older. Compared with 2010 the number of children would be 15% lower in 2050. For the potential labor force (i.e. those persons that are in the working age classes independently of they are employed or not) the reduction is -13%, while the retired persons will increase by +46% until 2050. As can be seen by the right hand side of Figure 2-3 the decline of the labor force differs for the European regions. In the Northern countries it remains nearly stable, while in Western countries it is reduced by about -7% and in Southern and Eastern countries by more than -20% until 2050 compared with 2010.

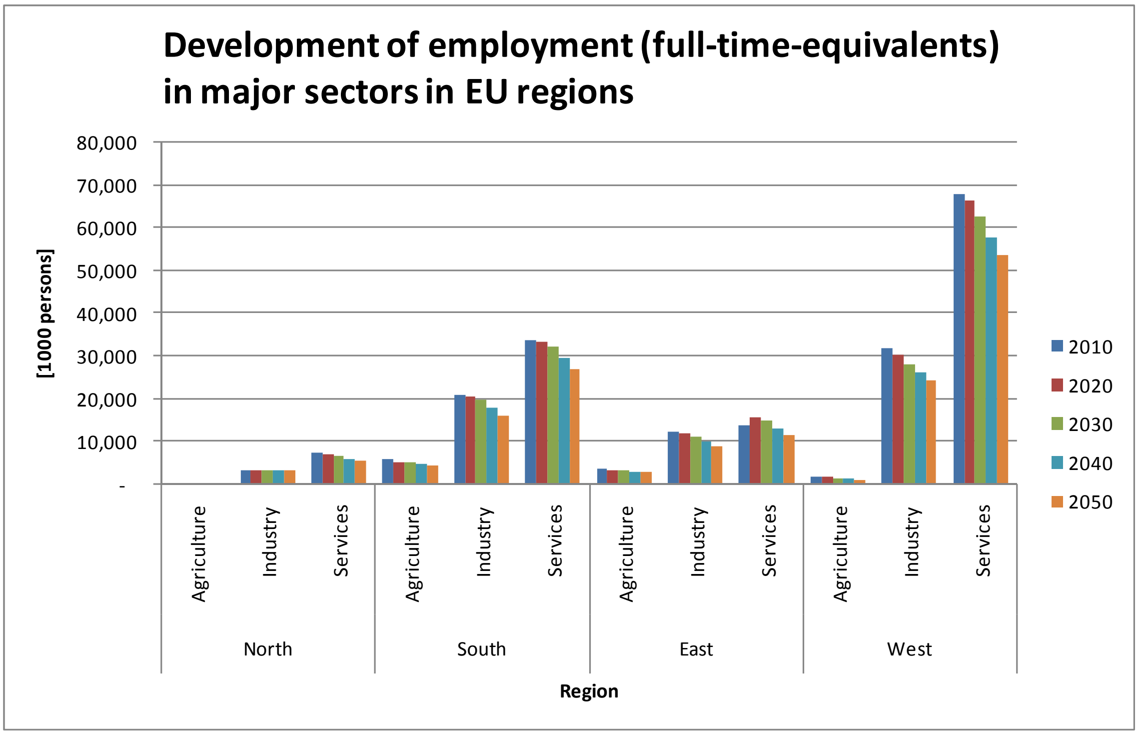


Source: ASTRA model reflecting the ADAM scenario framework.

Figure 2-3: Population structure and labor force in the EU regions

In terms of sectoral employment this leads to a somewhat surprising result, as shown in Figure 2-4. As expected, the agriculture sector looses employment (measured in full-time equivalents) in all regions, being largest in the Eastern countries with a reduction of -30%. However, apart from the industry sector in the Northern countries, which remains stable, and from the service sector in the Eastern countries, which in the first two decades increase their employment compared with 2010, both the industry and the service sectors reduce employment until 2050.

One major driver has been explained above with the potential labor force reducing significantly over time by -13%. Furthermore, activity rates also decrease slightly due to a number of developments e.g. more persons going to study and facing thus longer education periods as well as continued early retirement as it becomes increasingly difficult for older persons of the labor force (55 or more) to cope with the fast technical and knowledge development. Additionally, the share of part-time employment increases, which reduces the number of full-time equivalent employed persons.



Source: ASTRA model reflecting the ADAM scenario framework.

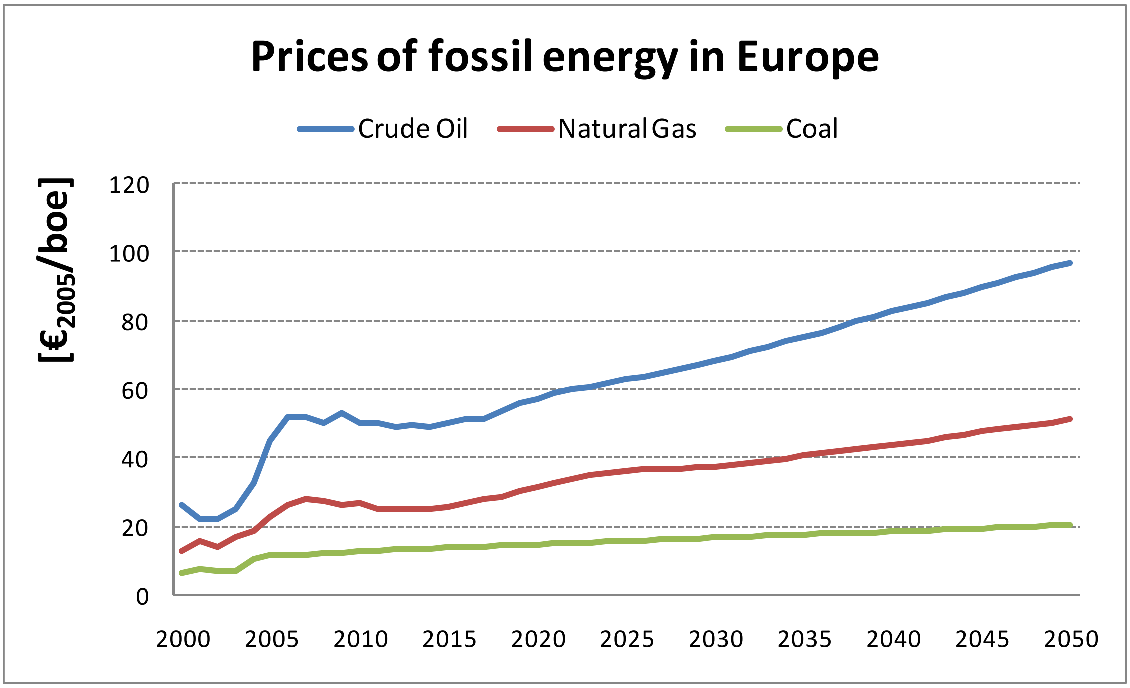
Figure 2-4: Development of employment in major sectors in Europe

2.3 Energy prices

The energy prices are provided by the POLES model and are used in the sectoral bottom-up models. This concerns the prices of crude oil and derived fossil fuels, e.g. gasoline, diesel, coal or heating oil. Electricity prices are estimated by the models of work package M1 independently.

Figure 2-5 presents the development of fossil energy prices in Europe. The prices reflect the global market concept or at least European market concept according to which basically the European countries all pay the same price for their fossil energy (which is mostly imported), such that differences in final energy prices (e.g. gasoline) would mainly result from taxation differences.

It can be observed that the price structure remains the same as today with crude oil being most expensive followed by gas and then coal. Compared with 2010 both the crude oil price and the natural gas price will increase by about +90% by 2050. The coal price increases by about +60%. This price path reflects an optimistic point of view, projecting the peak of world oil production around 2030 as well as assuming the feasibility of replacing reduced conventional oil production by unconventional oil such that the world oil production roughly remains stable until 2050. Given that other studies expect the peak of oil production between today and 2015 [e.g. EWG 2007] or at least report a sharp decline of production of mature oil wells of -5% per annum, which requires a new production capacity of 3.5 million barrels per day annually [IEA 2008], the fossil energy price path of oil and gas seem to be at the lower end of the possible scenarios.



Source: POLES model.

Figure 2-5: Prices of fossil energy in Europe in Reference Scenario

3 Methodological issues analysing mitigation options

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This section describes the ADAM-HMS (ADAM hybrid model system) both in its components i.e. the single models and in its application. It starts with the description of the global structure and the explanation of the integrated models. This is followed by an explanation of the data exchange and the data flows between the models. The final section highlights the objective of converging selected model elements during the course of simulating a scenario and the diffculties to obtain convergence.

3.1 The ADAM hybrid model system (HMS)

The basic concept underlying the ADAM-HMS is based on the following arguments: (1) it is feasible to link different types of models (e.g. top-down and bottom-up models), (2) it makes sense to link these models as each has specific strengths, and (3) the linkage of the models is more than the sum of the single pieces since it alleviates the limitations of the models e.g. by considering feedbacks that can not be considered just within one of the models.

An alternative to the linkage of separate models is the integration of the functionality within one model. Such an approach is taken by the POLES world energy system model, which besides a macro-economic model integrates all models of the ADAM-HMS into one integrated bottom-up model. Thus our work also included a comparison of the hybrid model system with the integrated approach for the energy system delivered by POLES. The comparison focusses on the bottom-up sectoral models and neglects that in POLES all scenarios consider the same economic development, while in the ADAM-HMS the economic drivers change between the scenarios (in particular GDP) as well as the economic structure.

3.1.1 Linking top-down and bottom-up models

Two basic types of models have been integrated into the ADAM-HMS: top-down and bottom-up models. The terms emerge from the way these models look at the economy and its different sectors and actors. Top-down models come from the macro-perspective i.e. GDP, national employment or household consumption. Usually they disaggregate their analysis then into a number of economic sectors e.g. agriculture, vehicle manufacturing, construction, banking etc. and describe the interaction between these sectors. Such a model would constitute a macro-economic model (or if the number of sectors is highly disaggregated one would also speak of a meso-economic model). The variables in such a model would mainly represent monetary values. The analysis using such a model would most often be called a (macro-) economic analysis.

Bottom-up models start from technologies and processes. By aggregating their results across technologies they provide statements on (parts of) economic sectors. E.g. a model that considers all the technologies for producing electricity in a country by describing the installation of the power-plants would be describing the electricity generation sector of that country. This could be equivalent to one sector in the top-down model or only to a part of such a sector. The variables in such a model would represent both physical values e.g. energy demand, tons of material and monetary values e.g. cost of the technologies. The analysis applying this type of model would be called a sectoral or partial-economic analysis.

The drawback of the first approach is that it lacks the technological foundation for the economic choices made in the different sectors, but it is able to consider the feedbacks of impacts between the sectors as well as the second round or indirect effects e.g. effects that occur because one sector stimulates the growth of GDP and via the demand side (i.e. consumption and investment) other sectors are also economically stimulated. The drawback of the second approach is that it lacks the interaction between the sectors as well as the second round effects, while it is able to describe the competition between different technologies and the structural change within a sector that is driven by the diffusion of new technologies.

The reason for linking top-down and bottom-up models is to overcome the individual drawbacks. The linked top-down model is able to consider technological details in the macro-economic analysis, while the bottom-up models receive the feedbacks from the other sectors and the second round effects from the macro-economy. Thus for our work package M1 it was decided to develop the linkage between a top-down model (i.e. ASTRA) and a number of bottom-up models (i.e. EFISCEN, MATEFF, RESIDENT, SERVE, ISIndustry, PowerAce, EuroMM).

3.1.2 Integration of models to form the ADAM-HMS

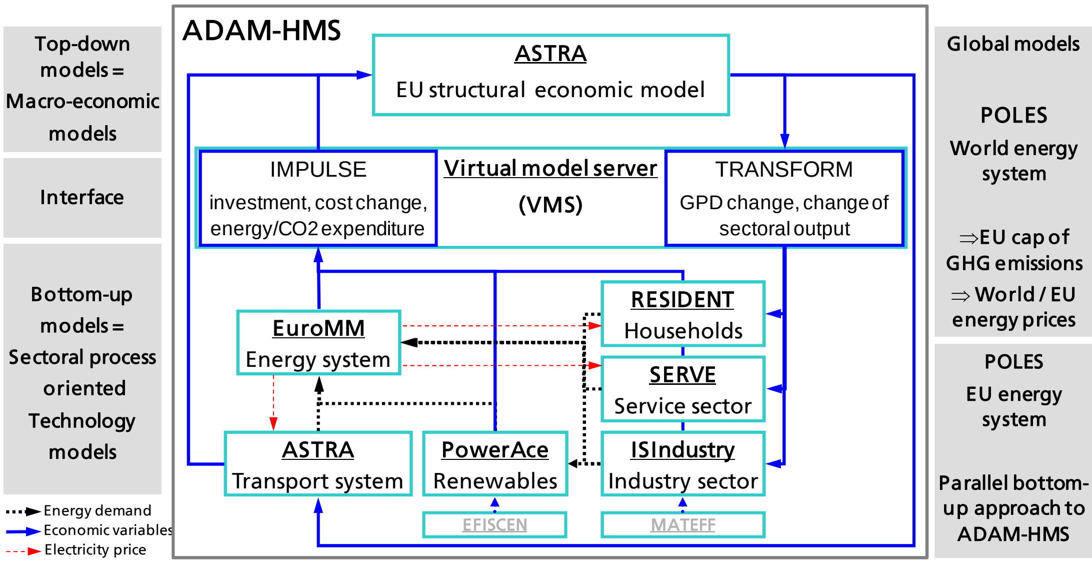
Figure 3-1 presents an overview of the ADAM-HMS and the linkages that have been developed between the models. The purpose of the different models in the ADAM-HMS is the following:

- **POLES**: world energy system model that delivers energy prices aligned with global energy demand as well as a GHG emissions path for Europe aligned with global mitigation activities, and a parallel bottom-up approach to the ADAM-HMS.
- **ASTRA**: EU structural economic model that calcluates the macro-economic effects of climate policy (top-down model applied in the ADAM-HMS).
- **RESIDENT**: bottom-up model describing the energy demand of the household sector for all purposes linked to housing (heating, electricity, etc.). Integrates the RESAppliance model.

- **SERVE**: bottom-up model describing the energy demand of the service sectors for all purposes besides transport (heating, electricity, etc.).
- **ISIndustry**: bottom-up model estimating the energy demand of basic industries and the manufacturing sectors.
- **ASTRA-Transport**: bottom-up model calculating the energy demand of the transport sector. Is directly integrated into the ASTRA model and thus the connection to ASTRA-Economics differs compared with the other bottom-up models.
- **PowerAce**: bottom-up model describing the market diffusion of renewables into the energy markets, in particular for electricity.
- **EuroMM**: bottom-up model modelling the full energy sector integrating the inputs of all final energy sector models.
- **EFISCEN**: forest model estimating the biomass potentials of EU forestry and providing them to PowerAce i.e. no full integration into the feedback loops of ADAM-HMS.
- **MATEFF**: basic materials and material efficiency model providing savings potentials of materials to the other models, in particular to ISIindustry. Not fully integrated into the feedback loops of ADAM-HMS.
- **Virtual model server** (VMS): is a tool that simplifies, structures and semi-automates the multilateral data exchange between various models.

Figure 3-1 presents a number of data flows between the models. These consist of three major types of information: energy demand, energy prices and economic variables. The core of the exchange of data between the bottom-up models consists of the estimated energy demand by the different sectors (black dotted arrows), which is provided to PowerAce and EuroMM from the final energy sectors: residential, services, industry and transport. In turn EuroMM calculates a new mix of power plants and a new electricity price using the world energy prices of POLES. The new electricity price is fed back to the final energy models (red dotted arrows).

The second major group of exchange data concerns the economic variables. These are needed to close the feedback loop between the bottom-up models and the top-down models (blue solid arrows). In the direction from top-down to bottom-up models the data to be transferred concerns mainly the drivers shaping the demand in the bottom-up models. Such drivers would be the GDP or income, the population, the trade flows, the sectoral output and the sectoral employment. In the direction from bottom-up to top-down models the data consists of investments that are induced by the mitigation policy as well as the avoided investment (e.g. reduced investment in coal power plants), changes of energy cost and/or energy expenditures in the different sectors, the reductions of imports of fossil energy, the prices and/or expenditures for CO_2 (or carbon). The interface via which the data is exchanged is the Virtual Model Server (see section 3.2.1).



Source: ADAM M1, Fraunhofer-ISI

Figure 3-1: ADAM hybrid model system, POLES parallel approach and global framework

Three issues usually have to be solved when linking or integrating separate models into a model system: (1) common boundary conditions for joint input variables, (2) overlaps between different models, and (3) in-/output relations between the models.

The common boundary conditions were defined by the ADAM work package Scenarios before the start of the simulations with the ADAM-HMS. The boundary conditions include the scenario set-up, population, GDP and energy prices as described in section 2. Such a common framework is simple to integrate for those models that use these variables as exogenous input. They mainly need to replace their exogenous input to fit to the common framework. Other models that endogenously calculate part of these variables have to be re-calibrated. Usually they would not be able to reproduce exactly the same development as given by the common framework. For instance this would be the case for the ASTRA model and its adaptation to the ADAM GDP trend.

In case of overlaps between the models either all models are calibrated to the same development, or one model is defined as the leading model that provides the results for the overlapping part and the other models have to comply as closely as possible to these results. The number of overlaps has been very limited in the ADAM-HMS, because the selection of models was made such that specialised sectoral models were chosen that would not overlap.

The main overlap was between PowerAce and EuroMM for the renewable energy, for which PowerAce was used as the leading model.

In-/output relations exist when model A calculates a variable as output, which is exogenous in model B such that model B can easily include the output of model A as new exogenous input and on this basis model B would then produce new results.

3.1.3 Brief description of the single models

The following paragraphs briefly describe the purpose and approach of each model. Detailed descriptions of all models have been provided in our deliverable D1 [Jochem et al. 2007].

3.1.3.1 ASTRA macro-economic model

ASTRA is a strategic integrated assessment model that includes a core macro-economic model, a trade model and a population model for the EU27+2 countries. The model builds on recursive simulations following the system dynamics concept and enables to run scenarios until 2050. The economic model applies different theoretical concepts e.g. endogenous growth by linking total factor productivity to investments, neo-classical production functions that consider capital, labor and the total factor productivity, Keynesian consumption driven and export driven investment functions. The macro-economic model consists of five elements: supply side, demand side, an input-output model based on 25 economic sectors, employment model and government model [Schade 2005].

3.1.3.2 RESIDENT model

RESIDENT-E06 is a bottom-up simulation model for the determination of long-term final energy demand for heating and hot water in the residential sector. The heating part is based on floor area, specific heat demand, and efficiency of heating system. The buildings are divided into two types (single family and multifamily house-holds), and three age classes (old, intermediate, new). For every such building (6 combinations), there is a specific heat demand which includes some retrofitting. The share of energy carriers (with yearly substitution factors) and the mean efficiency is only divided in the two types (single and multifamily).

The hot water part simulates the residential demand of hot water starting from the number of people and the specific demand of hot water (litre per person). The final energy (for different fuels) is then calculated with assumptions about share of final energies and using the efficiency of the different heating systems. The model applies the cohort methodology to describe the development of houses and technologies over time. It is implemented in Excel.

As add-on to RESIDENT the RESAppliance model calculates the energy demand of the most relevant household appliances by specific diffusion rates (number of appliances per household) and specific annual energy consumption values per appliances. The latter develop over time, both in the mitigation scenarios and the reference scenario.

3.1.3.3 SERVE model

SERVE-E06 is CEPE's energy demand model for the service sectors of the European countries. It is based on SERVE that was developed in the 1990s and has been used by CEPE on behalf of the Swiss Federal Office of Energy (SFOE) for the elaboration of new energy demand scenarios for Switzerland. Detailed accounts can be found in [Aebischer et al. 1996, Aebischer 1999, Aebischer et al., 2006].

SERVE is a bottom up simulation model implemented in Excel, that calculates the medium- and long-term final energy demand. A key feature of the model is to apply cohort models that depict the development of drivers and technological parameters over time. Within the ADAM project, it was further developed and applied to Europe (EU27 plus Norway, Switzerland), incorporating data and features from models and databases such as ODYSSEE, MURE, POLES, and others.

3.1.3.4 ISIndustry model

The model ISIndustry belongs to the class of energy system or bottom-up models, which means the calculation is based on technological information about distinct conservation options and industrial processes. Two different kinds of technology groups are considered, process-specific technologies and cross-cutting technologies. Blast furnaces in steel making are one example for the former; these are sector- and even process-specific. In contrast, cross-cutting technologies are widespread over very different industrial sectors. Examples are electric motors or lighting equipment, which are applied throughout all industrial sectors.

For process-specific technologies, the main driver is the projection of physical production (e.g. tonnes of crude steel from blast furnaces). The 40 most energy- and greenhouse gas-intensive processes are considered separately in the model. For each of these processes, the specific energy consumption/GHG emissions and the physical production output per country are model parameters.

Although cross-cutting technologies are usually smaller, there are huge numbers involved due to their widespread application and so they are responsible for a huge share of industrial electricity consumption. Electric motors and lighting account for more than 70% of industrial electricity consumption. They are implemented in the model as a share of the total sector's electricity consumption and their main driver is the projected development of value added per industrial sector.

The technological detail of the model allows the simulation long-term industrial energy demand based on distinct technological energy efficiency options, allowing for the main economic trends.

3.1.3.5 ASTRA transport model

The integrated assessment model ASTRA incorporates its own bottom-up transport model consisiting of two classical 4-stage transport models for passenger and freight transport, vehicle fleet models, transport energy and emission models. The advantage of the ASTRA transport model is that although it is implemented as classical 4-stage model, it considers endogenous reactions on all stages i.e. there is no fixed generation and no fixed OD matrix. The vehicle fleet models include a discrete choice component to decide on the chosen engine technology and car size depending on the parameters of the vehicles and the socio-economic drivers. Development of technologies and ageing of vehicles is based on cohort models.

Due to the integration with the economic models of ASTRA the changes in the economic system immediately feed into changes of the transport behaviour and alter origins, destinations and volumes of European transport flows. The ASTRA model has been applied in various transport policy studies (e.g. pricing, infrastructure, integrated policy programmes), climate policy analysis in general and in the transport sector [e.g. Krail et al. 2007].

3.1.3.6 PowerAce-ResInvest model

The agent-based sector model PowerACE-ResInvest simulates the future development of energy conversion technologies using renewable energy sources (RES) in the electricity sector. Capacity expansion decisions of RES-technologies are modelled from an investor's perspective. The corresponding investment decisions are mainly driven by the heterogeneous techno-economic characteristics of RES on the one hand and on available financial support for RES-technologies on the other hand. In turn, techno-economic characteristics are represented by cost-resource-curves, describing a combination of the available resource potential and the corresponding electricity generation costs. To cite an example, detailed cost-resource-curves have been derived combining land availability and wind regimes in a geographical information system for wind onshore energy. Technology options are integrated dynamically into the model taking into account future cost developments of RES-technologies in terms of experience curves.

3.1.3.7 EuroMM model

The European Multi-regional MARKAL (EuroMM) energy-conversion model is a bottom-up, perfect-foresight optimization model. EuroMM is part of the MARKAL (MARKet ALlocation) family of models that is typically used to determine the least-cost energy system configuration over a given time horizon under a set of assumptions about technologies, resource potentials and demands [Fishbone et al. 1983, Loulou et al. 2004].

EuroMM provides a detailed representation of technologies in the electricity and heat production and fuel conversion sectors in Europe, including carbon capture and storage (CCS) and thermal power plant cooling system technologies, along with trade networks for energy carriers. The model represents 18 distinct regions covering the 27 EU member states plus Norway and Switzerland, and is calibrated to 2005 statistics with a time horizon up to 2050 [see also Jochem et al., 2007].

The EuroMM energy-conversion model is used to compute impacts of climate change on the energy conversion sector as well as to analyze policy instruments, such as carbon taxes or emission targets and their related effects.

Limitations: EuroMM relies on uncertain assumptions regarding future potential technology deployment rates and exogenous technological learning. The model uses the perfect foresight optimisation approach assuming perfect information and limited transaction costs. Furthermore, EuroMM only partly identifies the impacts from climate change and the necessary adaptation needs since it lacks a representation of detailed spatial impacts and extreme events.

3.1.3.8 EFISCEN model

Forestry projections for a base case scenario were produced using the European Forest Information SCENario model (EFISCEN). EFISCEN can be used to give projections of wood production and carbon stock changes in tree biomass in European forests down to the forest type and NUTS2 level [Pussinen et al. 2001, Nabuurs et al. 2007, Schelhaas et al. 2007]. EFISCEN consists of a whole tree biomass module, a soil module and a wood products module. Projections made with EFISCEN are initialised making use of detailed national forest inventories that were specifically gathered for this purpose from National forest inventory institutes.

For each country, projections are made by forest types. Forest types are distinguished by four characteristics, the tree species, the site quality, the region where the forest is situated (mostly NUTS2 regions) and the owner of the forest. Information from EFISCEN can be aggregated to any level. For this analysis, data was aggregated on a country level. We provide projections on wood available for the paper and conventional wood industry and wood available for bio-energy.

EFISCEN is an area-based matrix model that simulates the dynamics of the stemwood volume in a forest [Schelhaas et al. 2007]. For other tree organs as leaves, branches and roots, a detailed biomass expansion database is incorporated. For each forest type that is distinguished in the input data (which might be according to species, region, site class and owner), a separate matrix is set up. One matrix consists of 60 age classes of 5 year time steps and 10 volume classes with time steps that vary depending on the forest under study.

Aging of the forest is simulated by moving area to a higher age class, while growth is simulated by moving the area to a higher volume class. Transitions are derived from increment figures from the input data, or from growth and yield tables. These transitions can be changed over time to simulate changes in growing conditions, like climate change.

3.1.3.9 MATEFF model

The MATEFF model simulates energy-intensive materials and products. MATEFF allows for the idea that energy-intensive materials can be reduced in their specific weight, but still perform their function in given products and investment goods by improved design or material properties. MATEFF also covers material recycling and material re-use as well as material substitution including materials made out of biomass. The materials covered by the model are all energy-intensive materials covered by the industrial model ISINDUSTRY and also at the same country level of the European countries.

MATEFF is based on economic and demographic data from the macroeconomic E3ME model of Cambridge Econometrics (up to 2030) and the ASTRA model from the Fraunhofer Institute of Systems and Innovation Research, ISI (from 2030 to 2050). The wood potential from forests is taken from results of the EFISCEN model of University of Wageningen.

As an important driver of energy demand in industry, the production of energy-intensive products and materials is quite important. The development of these energy-intensive products is often not easy to relate to the economic production value when value added of these basic materials increases substantially over time; this is often the case due to quality improvements or additional services of the related industrial sector and not to the quantities produced. It is important, therefore, to relate the specific energy demand of those materials to their physical production and not to gross or net production values.

3.1.3.10 POLES model

POLES – Prospective Outlook for Long term Energy Systems model - provides a complete system for the simulation and economic analysis of the sectoral impacts of climate change mitigation strategies. The POLES model is a dynamic Partial Equilibrium Model, essentially designed for the energy sector but also including other GHG emitting activities, with the 6 GHG of the “Kyoto basket”. The simulation process is dynamic, in a year by year recursive approach that allows describing full development pathways from 2005 to 2050.

The use of the POLES model combines a high degree of detail on the key components of the energy systems and a strong economic consistency, as all changes in these key components are at least partly determined by relative price changes at sectoral level. As the model identifies 46 regions of the world, with 22 energy demand sectors and about 40 energy technologies – now including generic Very Low Energy end-use technologies – the description of climate policy induced changes can be quite extensive.

As far as induced technological change is concerned, the model provides dynamic cumulative processes through the incorporation of Two Factor Learning Curves, which combine the impacts of “learning by doing” and “learning by searching” on the technologies’ improvement dynamics. As price induced diffusion mechanism (such as feed-in tariffs) can also be included in the simulations, the model allows for a taking into account of the key drivers to the future development of new energy technologies.

One key aspect of the analysis of energy technology development with the POLES model is indeed that it relies in all cases on a framework of permanent inter-technology competition, with dynamically changing attributes for each technology. In parallel, the expected cost and performance data for each key technology are gathered and examined in the /Techs-DB/ database that is developed at LEPII-EPE for any modelling and policy-making purpose.

Finally one can emphasise the fact that, although the model does not provide the total indirect macro-economic costs of mitigation scenarios, it can produce reliable economic assessments that are principally based on the costs of developing low or zero carbon technologies, thus benefiting from a detailed engineering representation.

Developed under different EU research programmes (JOULE, FP5, FP6), the model is fully operational since 1997. It has been used for policy analyses by EU-DG Research, DG Environment and DG TREN, as well as by the French Ministry of Ecology and Ministry of Industry

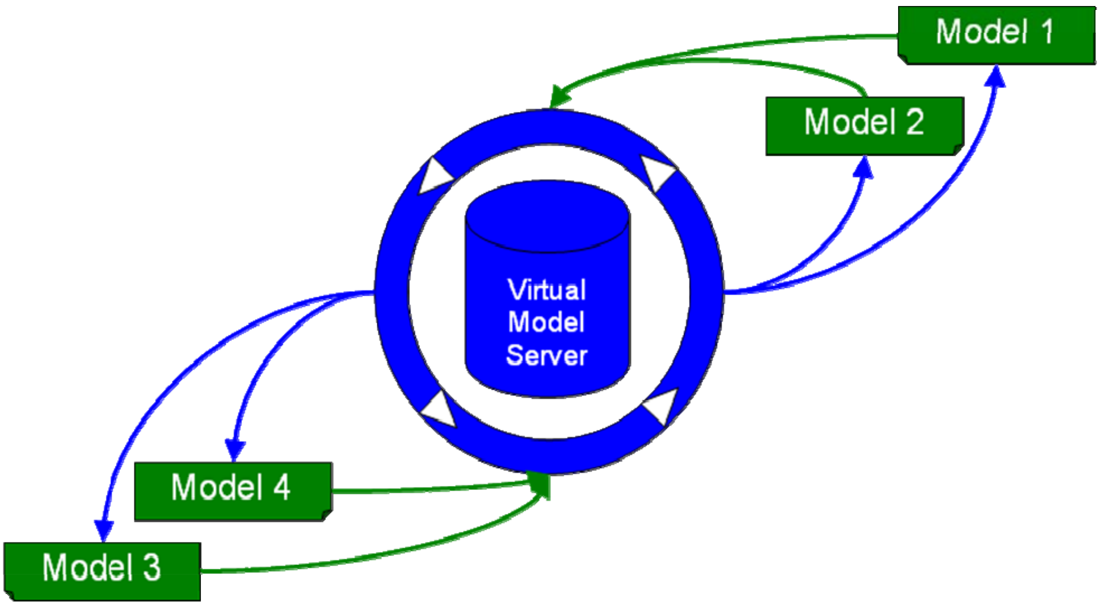
3.2 Data exchange system

Managing and automating the exchange of data between the models was a major challenge within the ADAM M1 project, since 7 to 9 models covering different fields of specialisation were exchanging data. This exchange had to be done repeatedly, resulting in iterations of model simulations in order to achieve convergence, harmonise the model’s assumptions and generate consistent results. Manual transformation of the repeatedly exchanged huge amounts of data would have been highly repetitious work, which naturally is extremely error-prone and time consuming.

Therefore, a configurable software – the Virtual Model Server (VMS) – was developed for the data exchange and used as described in the two subsequent sections and in more detail in Annex 16.1. The full documentation is provided in [Helfrich/Reusch 2009].

3.2.1 Virtual Model Server – automated data exchange

The virtual model server – VMS – was developed by Fraunhofer-ISI in order to automate complex data transformations when passing data from one model to another and to manage sequences of transformation steps for running models in series, each model using the output of its predecessor as input. With this software the iteration of model simulations is also possible, i.e. a sequence of simulations in which the starting model eventually receives data from another model calculated based on the first models results. This is depicted as an abstract example in Figure 3-2. Here, models 1 and 2 start the iteration and send their resulting data to the VMS. The server transforms the data into the format needed by models 3 and 4, each receiving different input formats and different subsets of the data provided by models 1 and 2. Then, models 3 and 4 can run their simulations and send their results to the VMS, for the compilation of input for the next models in the sequence, in our example models 1 and 2, which started the sequence. These two can then calculate again and continue the simulation loop.



Source: Fraunhofer-ISI

Figure 3-2: Virtual Model Server – abstract data flow

3.2.1.1 Technical details

The VMS was developed purely in *Java* as a web application for the *Tomcat Application Server* with a *MySQL database* as data storage backend, all following the open source philosophy. It builds on a variety of open source libraries for various functionalities. Most importantly, it uses *Hibernate* along with *Spring* for persistent data.

3.2.1.2 Design philosophy

The development of the software was driven by the idea of creating a highly configurable tool, which should not be specific to certain interfacing and transformation tasks. This design enables the adoption of model output transformation definitions without changing neither the source code of the source model nor of the target model. All transformations are defined using an XML subset specificallydeveloped for this purpose. With this design philosophy, we managed to create a highly reusable tool as it is possible to integrate new models into the data exchange. Thus the VMS enormously facilitates the data transformation tasks when integrating two or more models into an interacting hybrid model system.

3.2.1.3 Functionality

For defining the transformations, three major parts are necessary. First, for each model all relevant input attributes have to be defined. This is done in the *model definition*. Second, the data transformations have to be defined on a variable by variable basis, describing for each input variable of the subsequent model in the iteration sequence how it is composed of the output variables of the preceding models. This is the *transformation definition*. And third, the sequence of transformations has to be defined in the *sequence definition*. The latter is important when the sequence of running the models plays a role for generatimg results, which is most often the case.

Model definition

For each model, a definition file is compiled containing the following information:

- Variables and the dimensions they are defined on,
- Dimensions e.g. indexes for countries or economic sectors,
- Timeframe and time intervals as the models run on different time intervals, and
- File format used for transferring data.

Transformation definition

The core functionality of the VMS is the ability to transform data that has to be exchanged between two models in an automated way. Therefore, a definition language was developed in order to describe the transformations based on XML. VMS features the following operations:

- Basic arithmetic operations: addition, subtraction, multiplication, division.
- Dimension mapping, i.e. the definition of how one dimension of model A refers to a related but differently named or aggregated dimension of model B.
- Aggregating dimensions, i.e. reducing two- or mutli-dimensional variable to a lower number of dimensions.
- Splitting dimensions, i.e. the inverse operation of the aggregation, producing e.g. a two-dimensional variable based on a one-dimensional variable with fixed split factors for the elements of the new dimension.
- Intermediate variables for calculating various steps with the VMS, where the output of one calculation is the input for the next calculation.
- Index calculation, i.e. the ability to calculate an index on a given base year of a variable.

- Temporal interpolation, i.e. filling years not covered by the output of model A but needed in the subsequent model B. This is done as linear interpolation.

Sequence definition

Eventually, the order in which

- the individual models calculate results,
- deliver the results to the VMS,
- the VMS transfers these results and hands them over to the next model

has to be defined. This is done in the sequence definition, which is stored in another set-up file.

3.2.2 Data flow between models

Using the Virtual Model Server described in the previous section, a large amount of data was exchanged between the various models collaborating during the project. The details about which data was exchanged in what sequence is described in this section. Table 3-1 gives a high level overview of which data is exchanged by the individual models. As can be seen there, PowerACE delivers data to EuroMM and ASTRA. ISIndustry provides data to PowerACE, EuroMM and ASTRA. CEPE models hand over data to PowerACE, EuroMM and ASTRA. From EuroMM, data is transferred to PowerACE, CEPE models and ASTRA. From ASTRA, data is carried over to PowerACE, ISIndustry, CEPE models and EuroMM. Most data is provided as yearly figures, with the exceptions of EuroMM data, which is provided (or required) as 5 year aggregates or data for every 5th year. The details of which data is transferred between the models for each direct bilateral link are explained in Annex 16.1.

Table 3-1: Data flow between models – high level overview

to / from	Power ACE	ISIndustry	CEPE models	EuroMM	ASTRA
Power ACE		✘	✘	✓	✓
ISIndustry	✓		✘	✓	✓
CEPE models	✓	✘		✓	✓
EuroMM	✓	✘	✓		✓
ASTRA	✓	✓	✓	✓	

Source: Fraunhofer-ISI, CEPE models: RESIDENT, SERVE, RESAppliance

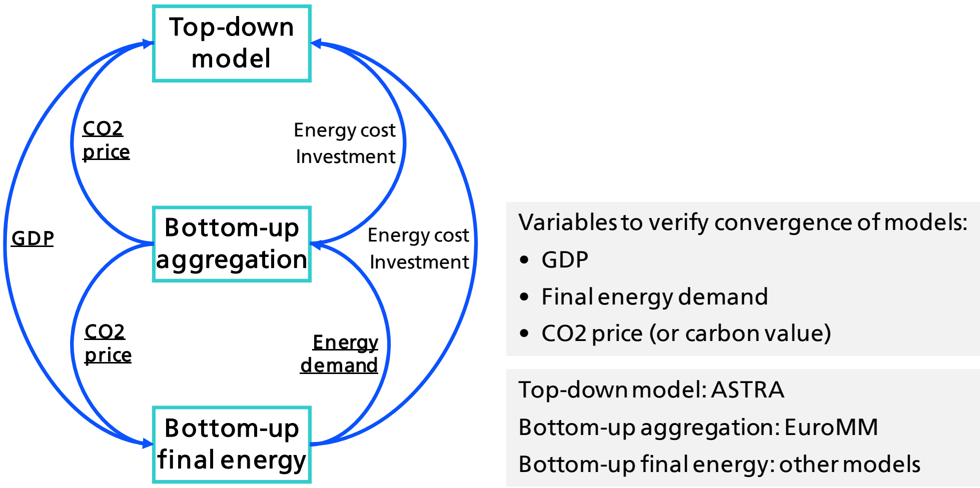
Two examples of data flows are given in the following paragraphs. The full list of flows is provided in Annex 16.1.

- Example 1: EuroMM provides the CEPE models with prices for electricity. These are provided per country both as separate electricity prices for industry as well as for households. Since the two models use different country groups, a mapping from the countries of EuroMM to the countries of the CEPE models had to be defined. Further, the currency had to be converted from US$ 2000 to Euro 2005.
- Example 2: ASTRA delivers value added and employment to the CEPE models. The data is disaggregated per country and per sector. Both countries and sectors are defined differently in the two models, therefore, mappings for both dimensions were developed. Both variables were delivered to CEPE as index variables with the value of 2004 as a base year.

3.3 Simulation and convergence of the models in ADAM-HMS

As explained above simulating the ADAM-HMS requires an iterative process that follows a pre-defined sequence in terms of at which part of the sequence a model receives input and when it has to deliver its output. During each iteration a model always receives the same input variables and delivers the same output variables, but in each iteration the values of these variables change. The question of convergence of the results of the various models then becomes: when the difference between the values of the variables within two subsequent iterations is small enough to decide that the models have converged and thus that their individual results are consistent?

Figure 3-3 presents the conceptual structure of the iterations for the three building blocks of the ADAM-HMS (top-down model, bottom-up final energy models and bottom-up aggregation model) and the major variables relevant for the analysis of convergence (GDP, energy demand and the CO_2 price). An iteration now starts with GDP, provided from the scenario framework, and a CO_2 price provided by the POLES model. Based on this information the final energy demand models generate energy demand, which is aggregated to total final energy demand in the bottom-up aggregation model (EuroMM) that simulates the technologies applied in the energy conversion sector and derives a new CO_2 price. All bottom-up models deliver changes of energy cost and sectoral investments to the top-down model (ASTRA), which estimates a new GDP. With the new GDP and the new CO_2 price the subsequent iteration starts generating a new energy demand and again new CO_2 prices and GDP. Convergence is achieved when between two subsequent iterations GDP, CO_2 price and energy demand does not change at all to within the specified tolerance.



Source: Fraunhofer-ISI

Figure 3-3: Convergence in the simulations of the ADAM-HMS

The three major variables to assess convergence display different sensitivities to the remaining differences between the models. GDP and energy demand converge rapidly i.e. in the first 3 to 4 iterations they incorporate most of the adaptations required to come to convergence. Later iterations change these only marginally. However, the CO_2 price is much more sensitive (as also shown in section 12). The reason is that it is calculated on the base of the marginal cost concept in an optimisation model, which means that when scarcity occurs and the CO_2 price shifts to the right hand side of the cost curve, the CO_2 price change between two iterations occurs on the exponential part of the curve and thus minor changes of CO_2 quantities lead to sharp price changes.

4 The integrated global energy model POLES and its projections for the Reference and 2°C scenarios

Authors: Silvana Mima, Patrick Criqui

The development of a Reference scenario is essential for the overall consistency of the policy analysis. The Reference scenario aims to integrate the most up-to-date information and expectations about demographic growth, its regional distribution, major economic and technology trends (in GDP trends, sectoral allocation of production, technological progress, R&D investment) and availability of depletable resources. From this limited set of exogenous trends, the POLES model projects the relevant energy and environmental variables up to 2050.

The POLES Reference projection in the ADAM study provides an image of the energy scene up to 2050 resulting from the continuation of on-going trends and structural changes in the world economy. The model provides a tool for the simulation and economic analysis of world energy scenarios under environmental constraints. It is a partial equilibrium model, with a dynamic recursive simulation process. From the identification of the drivers and constraints in the energy system, the model allows us to describe the pathways for energy development, fuel supply, greenhouse gas emissions, international and end-user prices, from today until 2050.

The approach combines a high degree of detail in the key components of the energy systems with a strong economic consistency, as all changes in these key components are largely determined by relative price changes at sectoral level. The model identifies 47 regions of the world, with 22 energy demand sectors and about 40 energy technologies – now including generic “very low energy” end-use technologies.

The main exogenous inputs to the Reference projection relate to world population and economic growth as the main drivers of energy demand, oil and gas resources as critical constraints on supply, and the future costs and performance of energy technology that define the feasible and cost-effective solutions. In all cases, the projected trends extrapolate existing structural changes; this in no way implies a uniform development of the world economic and energy system, as illustrated below.

An important aspect of the projections performed with the POLES model is that they rely on a framework of permanent inter-technology competition, with dynamically changing attributes. The expected cost and performance data for each key technology are gathered and examined in a customised database that organises and standardises the information in a manner appropriate to the task.

Finally, in the ADAM Reference case, for the first time the impacts of climate change on the energy system in the cases of building heating and cooling are introduced as endogenous variables in the model. Analyses of the corresponding consequences of climate change are thus presented as well.

Two 2°C scenarios, one corresponding to 450 and another to 400 ppm are analysed in section 4.2. Each scenario can be described as the set of economically consistent transformations of the initial Reference case that is induced by the introduction of policy constraints. Although the model does not calculate the indirect macro-economic impacts of mitigation scenarios, it does produce robust economic assessments based on the sectoral costs of implementing new technologies, which benefit from a rigorous examination of the engineering and scientific fundamentals.

4.1 Assumptions and methods of the Reference Scenario

4.1.1 Major assumptions

4.1.1.1 Population and economic growth in ADAM projections

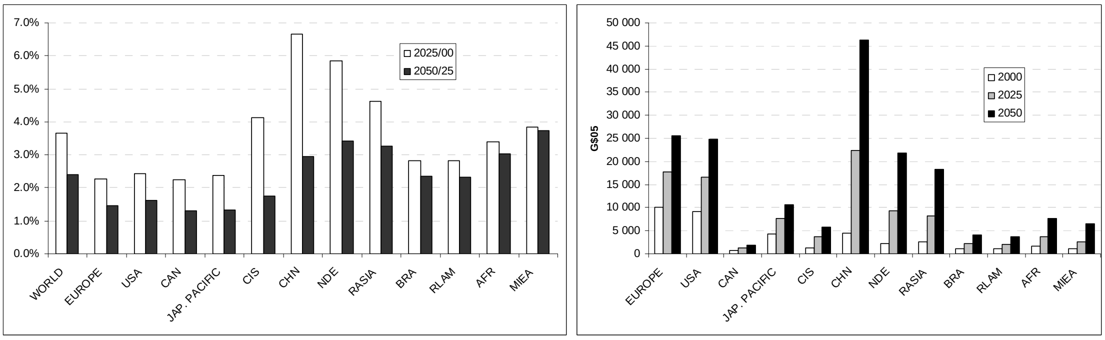
By 2050, world population will stabilise at 9 billion people. In this study, GDP is expected to be multiplied by a factor of 4 to 2050. This means that the world economy is projected to grow at 3.6 %/year until 2025 and then to slow down to an average of 3 %/year between 2000 and 2050. The slower growth in the second part of the period is the combined consequence of a falling population growth rate – or even a decrease in some regions – and of lower per capita GDP growth, in all regions except the Middle East and Africa (see Table 4-1 and Table 4-2 below).

Table 4-1: World population and economic growth in ADAM projections

	2000	2025	2050	Annual % change 2025/00	2050/00
Key Indicators					
Population (Millions)	6078	7896	9066	1.1%	0.8%
GDP (G$05)	40903	100157	181215	3.6%	3.0%
Per capita GDP ($05/cap)	6729	12684	19988	2.6%	2.2%

Source: POLES ADAM

The rate of future economic growth is broadly similar across industrialised regions; it is around 2.3 %/year from 2000 to 2025 and falls to 1.5 %/year from 2025 to 2050. As illustrated in Figure 1, economic growth is faster in developing regions: it is between 3 and 4 %/year in Africa and the Middle East over the period and a little less in Latin America; in Asia it falls steeply from the current 6.7-4.6 %/year to 3 %/year between 2025 and 2050. This largely reflects the end of the rapid catching-up process currently experienced by Asian economies and the economic slowdown consequent to the rapid ageing of the population in China. European GDP grows on average by around 1.9 %/year throughout the period. This growth rate is slightly higher than that of Canada and Japan-Pacific (+1.8 %/year), but it remains lower than the growth rate of USA (2 %/year).



Source: POLES ADAM

Figure 4-1: Economic growth, world and main regions

National growth rates vary substantially in Europe, particularly during the 2000/20 period from 1.8 %/year for Italy and Germany to 4.9 %/year for the Baltic countries. During the second half of the period, the growth rates converge to around 0.8-1.6 %/yr.

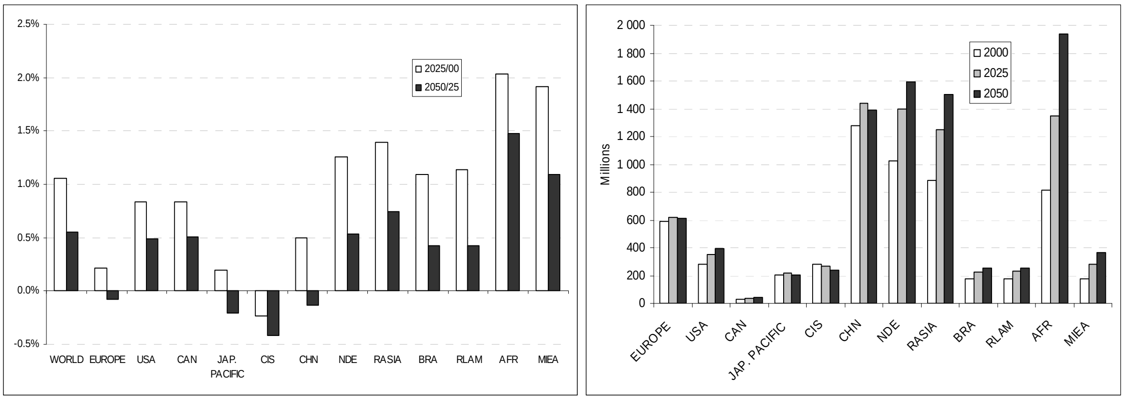
Table 4-2: Europe, EU27+Nor+Switz – GDP (in G$2005)

	2000	2010	2020	2030	2050	Annual % change 2020/00	50/20	50/00
Austria	206	245	300	344	400	1.9%	1.0%	1.3%
Baltic States	57	109	149	183	244	4.9%	1.7%	3.0%
Belgium & Luxemburg	269	330	406	483	624	2.1%	1.4%	1.7%
Bulgaria	47	73	94	116	168	3.6%	2.0%	2.6%
Cyprus, Malta and Slovenia	30	44	55	64	80	3.0%	1.3%	2.0%
Czech Republic	129	194	242	294	401	3.2%	1.7%	2.3%
Denmark	143	176	214	251	310	2.0%	1.3%	1.6%
Finland	123	153	188	224	293	2.1%	1.5%	1.8%
France	1392	1711	2124	2540	3345	2.1%	1.5%	1.8%
Germany	1975	2327	2839	3262	3969	1.8%	1.1%	1.4%
Greece	164	232	297	360	483	3.0%	1.6%	2.2%
Hungary	115	163	203	249	353	2.9%	1.8%	2.3%
Ireland	101	162	199	239	316	3.5%	1.6%	2.3%
Italy	1337	1599	1909	2133	2389	1.8%	0.8%	1.2%
Netherlands	396	469	592	704	889	2.0%	1.4%	1.6%
Norway and Switzerland	146	179	225	269	339	2.2%	1.4%	1.7%
Poland	356	508	682	887	1392	3.3%	2.4%	2.8%
Portugal	160	185	233	274	349	1.9%	1.4%	1.6%
Romania	118	192	258	331	514	4.0%	2.3%	3.0%
Slovakia	56	88	116	147	219	3.7%	2.1%	2.8%
Spain	738	954	1220	1455	1850	2.5%	1.4%	1.9%
Sweden	204	266	328	386	498	2.4%	1.4%	1.8%
United Kingdom	1352	1714	2123	2555	3460	2.3%	1.6%	1.9%
Rceu	82	125	173	229	371	3.8%	2.6%	3.1%
EU27+Nor+Switz	9613	12073	14995	17751	22885	2.2%	1.4%	1.7%
Europe	9695	12198	15168	17980	23256	2.3%	1.4%	1.8%
B4	6056	7351	8995	10490	13163	2.0%	1.3%	1.6%
SE	1093	1416	1806	2154	2763	2.5%	1.4%	1.9%
NE	1381	1735	2151	2557	3270	2.2%	1.4%	1.7%
EE	1165	1697	2217	2780	4060	3.3%	2.0%	2.5%

Source: POLES ADAM[3]

Regional variations in the trends of economic growth worldwide are derived in part from the underlying population dynamics, as shown in Figure 2. By 2025, the growth in population is negative in Europe, the Pacific OECD, the CIS and China. North and Latin America and Asia have low positive growth rates. After 2025, Africa and the Middle East are the only regions where growth exceeds 1 %/year.

3 Note: the EU27 countries are divided into four main economic/geographical areas : the Big Four – B4 (Germany, Italy, France,the United Kingdom), Southern Europe - SE (Spain, Portugal, Greece, Cyprus, Malta & Slovenia), Northern Europe – NE (Belgium & Luxembourg, Denmark, Finland , Ireland, the Netherlands, Sweden, Norway and Switzerland), Eastern Europe – EE (Austria, Baltic States, Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia).



Source: POLES REF ADAM

Figure 4-2: Population growth, world and main regions

The biggest changes concern Eastern Europe, with an acceleration of the population decrease after 2010 (Table 4-3).

Table 4-3: Europe, EU27+Nor+Switz, 4 areas – Population

						Annual % change		
	2000	2010	2020	2030	2050	2020/00	50/20	50/00
Austria	8	8	8	8	8	0.1%	-0.1%	0.0%
Baltic States	7	7	7	6	5	-0.4%	-0.7%	-0.6%
Belgium & Luxemburg	11	11	11	11	11	0.2%	0.0%	0.1%
Bulgaria	8	7	7	6	5	-0.8%	-1.0%	-0.9%
Cyprus, Malta and Slovenia	3	3	3	3	3	0.3%	-0.1%	0.1%
Czech Republic	10	10	10	10	8	-0.2%	-0.5%	-0.4%
Denmark	5	6	6	6	6	0.3%	0.1%	0.2%
Finland	5	5	5	5	5	0.2%	0.0%	0.1%
France	59	62	63	64	63	0.3%	0.0%	0.1%
Germany	82	83	82	82	79	0.0%	-0.1%	-0.1%
Greece	11	11	11	11	11	0.1%	-0.1%	0.0%
Hungary	10	10	10	9	8	-0.3%	-0.5%	-0.4%
Ireland	4	4	5	5	6	1.3%	0.5%	0.8%
Italy	58	58	57	55	51	-0.1%	-0.4%	-0.3%
Netherlands	16	17	17	17	17	0.3%	0.0%	0.2%
Norway and Switzerland	12	12	13	13	13	0.3%	0.1%	0.2%
Poland	39	38	38	36	32	-0.1%	-0.6%	-0.4%
Portugal	10	11	11	11	11	0.3%	-0.1%	0.1%
Romania	22	21	20	19	17	-0.4%	-0.7%	-0.6%
Slovakia	5	5	5	5	5	0.0%	-0.5%	-0.3%
Spain	41	44	44	44	43	0.4%	-0.1%	0.1%
Sweden	9	9	9	10	10	0.3%	0.2%	0.2%
United Kingdom	59	61	63	65	67	0.3%	0.2%	0.3%
Rceu	24	24	24	23	22	0.0%	-0.3%	-0.2%
EU27+Nor+Switz	495	505	506	503	484	0.1%	-0.1%	0.0%
Europe	519	529	530	527	506	0.1%	-0.2%	-0.1%
B4	258	263	265	266	260	0.1%	-0.1%	0.0%
SE	65	69	70	69	67	0.4%	-0.1%	0.1%
NE	62	64	66	68	68	0.3%	0.1%	0.2%
EE	134	132	129	124	110	-0.2%	-0.5%	-0.4%

Source: POLES ADAM

The second key driver of economic growth is the growth in per capita GDP that increases the mobilisation of labour and global productivity in the long term. The average growth rate in per capita GDP slowly decreases worldwide over the period and this is consistent with studies of long-term economic growth, which point to a secular trend of 1.5-2 %/year for average productivity growth. As shown in Table 2, the slowdown in per capita GDP growth is most noticeable in North America (although per capita GDP still increases up to $62,000/inhabitant in North America, thus remaining the highest throughout the period) and in Asia, where per capita GDP growth is more than halved, from the present impressive 3.2-6.1 %/year.

This pattern of economic and demographic growth mitigates the inequalities in income across the world in the long run. In spite of the drastic decrease in growth rates, China's per capita GDP catches up with that of Western Europe by the end of the century. Africa remains the most backward region; by 2050, its per capita GDP is 6 % of that of the USA. In 2050, the average per capita income in all developing regions except Africa is more than € 12 000.

The per capita GDP of the Europe increases 2.2 % each year, reaching two times and a half the current level at the end of the period.

Table 4-4: Per capita GDP, by world region ($2005/year PPP)

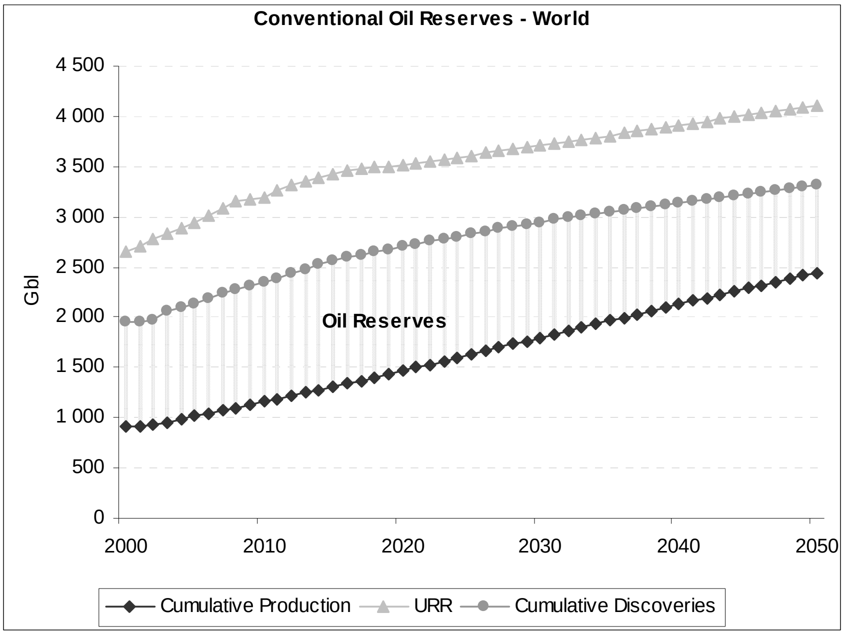
				Annual % change		
	2000	2025	2050	2025/00	2050/25	2050/00
WORLD	6 729	12 684	19 988	2.6%	1.8%	2.2%
EUROPE	17 160	28 612	42 033	2.1%	1.6%	1.8%
USA	32 018	47 484	62 801	1.6%	1.1%	1.4%
CAN	26 003	36 831	45 012	1.4%	0.8%	1.1%
JAP. PACIFIC	20 820	35 624	52 108	2.2%	1.5%	1.9%
CIS	4 775	13 883	23 828	4.4%	2.2%	3.3%
CHN	3 499	15 501	33 166	6.1%	3.1%	4.6%
NDE	2 220	6 721	13 671	4.5%	2.9%	3.7%
RASIA	3 002	6 595	12 192	3.2%	2.5%	2.8%
BRA	6 542	9 984	16 115	1.7%	1.9%	1.8%
RLAM	6 115	9 237	14 757	1.7%	1.9%	1.8%
AFR	1 957	2 731	3 993	1.3%	1.5%	1.4%
MIEA	5 923	9 450	17 962	1.9%	2.6%	2.2%

Source: POLES ADAM

4.1.1.2 World fossil fuel resources

The assumptions about oil and gas resources are critical because present market behaviour and a series of studies on resource availability suggest that the development of supplies to meet future increases in demand may face increasing difficulties. Any energy outlook for the long term has to deal with the expectation of an "oil peak" and a "gas peak", the date of which remains uncertain, but which some geologists expect soon. The consequent increase in prices may profoundly influence the development of competing energy technologies and reshape the future energy system at the world level. The POLES model provides a high level of detail for the evaluation of oil and gas resources and reserves, while all assumptions concerning ultimate recoverable resources (URS), discoveries, reserves and cumulative production and recovery rates have been reviewed by the Institut Français du Pétrole (IFP).

Cumulative production of conventional oil today is around 835 Gbl. The assumption in the ADAM POLES study is that 1 820 Gbl remain to be produced with current recovery rates, of which almost 1 037 Gbl have been discovered.



Source: POLES ADAM, Reference Scenario

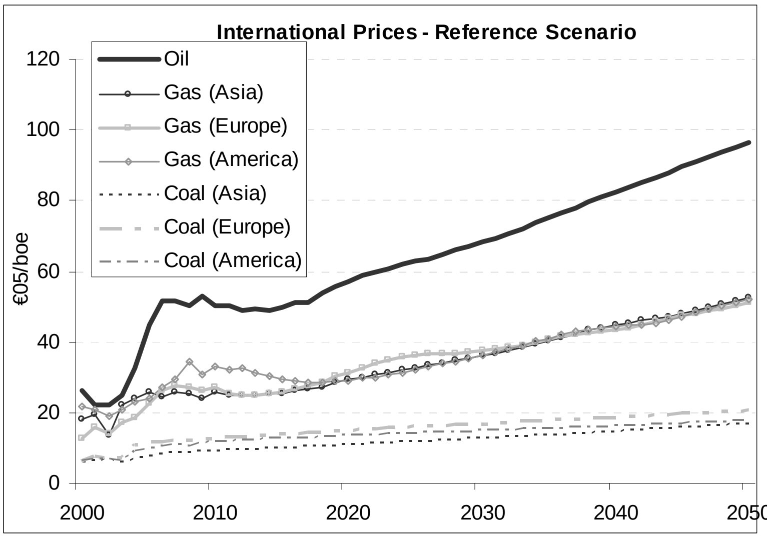
Figure 4-3: Ultimate Recoverable Resources, cumulative discoveries and production

Figure 4-3 presents the results of the simulation of the discovery and production of oil. The volume of ultimately recoverable resources increases in the period because of improved recovery rates, while cumulative discoveries depend on the exploration effort. The dynamic process for the development of reserves is visible in the Figure, because reserves are the difference between total cumulative discoveries and cumulative production. This process of reserve development and extension explains how total ultimate recoverable resources estimated by the USGS are extended from 2 600 Gbl today to nearly 4 000 Gbl in 2050; this of course has a major influence on the supply and demand balance for oil to 2050.

4.1.1.3 The geo-political and climate policy context

Assuming there is no climate policy, the Reference scenario represents a case study where the investment and consumption decisions of the economic agents are not modified by environmental regulations. Some limited geopolitical constraints to world oil development are taken into account in this scenario. It adopts the view that recent developments in the oil market – with prices between $ 100 and 140/bl in 2008 – do not only reflect a conjunction of exceptionally high demand and limited supply, but also signal important and permanent changes in resource accessibility and market behaviour. There are no longer any significant reserve margins of production capacity, suggesting that the tightness in supply will persist. This is not a consequence of insufficient reserves in the short term, but of restricted access for new developments and of growing scarcity in the longer term. Access is constrained in the crucial OPEC countries by inadequate investment in producing capacity and in non-OPEC countries by unexpected technical and political obstacles, with the CIS currently representing some exceptions.

The examination of the policies for oil development and foreign investment in the OPEC countries indicates that although there are still highly profitable opportunities, access is constrained in practice. The constant and significant increase in the oil production capacities of OPEC, which is needed to balance the world energy system in the next decades, will not be easy to achieve. This should even induce, in the medium term, stronger price volatility than the 2°C scenario exhibits. As a consequence, one can expect successive price shocks to limit demand and encourage alternative energy developments.



Source: POLES ADAM, Reference scenario

Figure 4-4: Prices of oil and gas in the Reference projection (€/bl)

However a full description of unstable price behaviour is hard to incorporate in a long-term model. However with the mechanisms of oil price formation included in the model, the Figure 4-4 illustrates the resulting trajectory of prices: the price of oil is expected to stabilise between 2008 and 2015 at a level of 50 €05/bl (i.e. approximately 70 $05/bl) and then increase again to more than 97 €/bl in 2050, as the resource constraints become tighter and tighter. This price level is needed, not so much to stimulate supply alternatives, which are in most cases already competitive, but to curb the trend in world oil demand, which would otherwise be clearly unsustainable.

This trend in the prices of oil and gas creates a structural cost advantage for coal. Resources of coal are much larger than those of oil and gas; they are also more dispersed and often located in large consuming countries. Consequently, the absolute increase in coal prices, when expressed in terms of oil equivalent, is expected to be far less than for hydrocarbons. In the Mitigation projection, coal prices roughly double from the current level, which is similar to the relative change expected for oil; but in terms of oil equivalent the price of coal is still only 21 $/bl in 2050, creating a huge cost advantage compared to oil and gas.

4.1.2 Methods used to reflect the impact of climate change[4]

The objective of this work has been to assess changes in energy use for heating and air conditioning under climate change. For that, it has been necessary to adapt the existing demand equations while taking into account the available data on the fundamental drivers of energy demand for heating and air conditioning in residential and service sectors, in the framework of a world where the average temperature may increase by +3.7°C compared to pre-industrial ages.

4.1.2.1 Modelling the impacts of climate change on heating demand

First of all, we isolate the demand for heating from the demand for substitutable energy (heating, cooking and sanitary hot water) in the residential sector. So, final consumption for substitutable energy in residential sector (**FCSENRES**) is split into two parts: on the one hand, the demand that cannot be impacted by climate change (**FCSENRESW**) and on the other hand the demand that will be affected (**FCSENRESH**):

$$\mathbf{FCSENRES_{[ALLC]} = FCSENRESW_{[ALLC]} + FCSENRESH_{[ALLC]}}$$

Shares (SHRES) of the part of heating demand on the substitutable energy, computed from data found in the existing literature, helps to accomplish this separation:

$$\mathbf{FCSENRES_{[ALLC]} = FCSENRES_{[ALLC]} * SHRES_{[ALLC]}}$$

$$\mathbf{FCSENRESW_{[ALLC]} = FCSENRES_{[ALLC]} * (1\text{-}SHRES_{[ALLC]})}$$

In the second stage we estimate the climate change impact on the heating demand (**FCSENRESHCC**). For that, the main drivers are heating degree days (HDD) provided by Timer/IMAGE. These data correspond to the Reference scenario (771 ppmv in 2050a, +3.7°C since pre-industrial ages).

$$\mathbf{FCSENRESHCC_{[ALLC]} = FCSENRES_{[ALLC]} * SHRES_{[ALLC]} * \frac{HDD_{[ALLC]}}{HDD_{2002}}}$$

[4] This section has been written taking into account the work accomplished by Julien MOREL.

In this way, the new demand for substitutable energy taking into account the climate change is:

$$\mathbf{FCSENRESCC_{[ALLC]} = FCSENRESW_{[ALLC]} + FCSENRESHCC_{[ALLC]}}$$

The same methodology is used for the service sector.

- Data

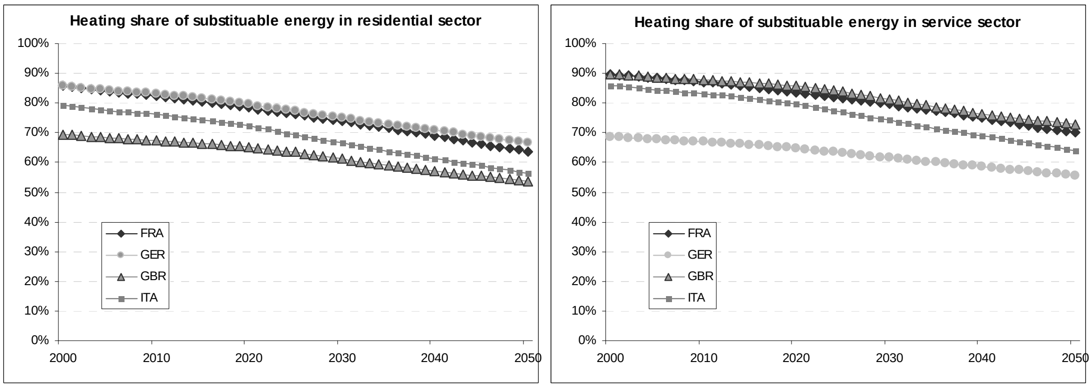
The data for the base year 2002, for **SHRES** and **SHSER,** for each POLES region, are constructed using several sources such as Enerdata, Eurostat (2005) for temperature correction. Then a logarithmic regression is applied between **SHRESH** and **HDD** and **GDP** (assuming the equivalence between spatial and temporal regression):

$$\mathbf{SHRES_{[ALLC,\ T]}} = \mathbf{SHRES_{[ALLC,\ T-1]}} * \left(\frac{\mathbf{GDPPOP_{[ALLC,T]}}}{\mathbf{GDPPOP_{[ALLC,T-1]}}}\right)^{0.06} * \left(\frac{\mathbf{HDD_{[ALLC,T]}}}{\mathbf{HDD_{[ALLC,T-1]}}}\right)^{1.58}$$

([5])

$$\mathbf{SHSER_{[ALLC,\ T]}} = \mathbf{SHSER_{[ALLC,\ T-1]}} * \left(\frac{\mathbf{GDPPOP_{[ALLC,T]}}}{\mathbf{GDPPOP_{[ALLC,T-1]}}}\right)^{0.02} * \left(\frac{\mathbf{HDD_{[ALLC,T]}}}{\mathbf{HDD_{[ALLC,T-1]}}}\right)^{1.47}$$

Figure 4-5 shows the example of heating shares of substitutable energy in the residential and service sectors in "Big Four" EU countries.



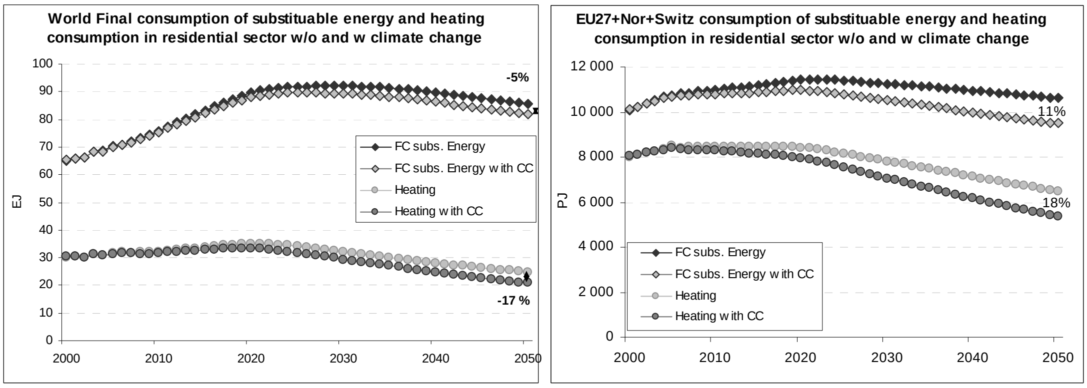
Source: POLES ADAM, Reference scenario

Figure 4-5: Heating shares of substitutable energy in residential and service sectors in Big Four countries

5 The coefficient of determination is respectively 0.85 and 0.82 for the residential and service sector.

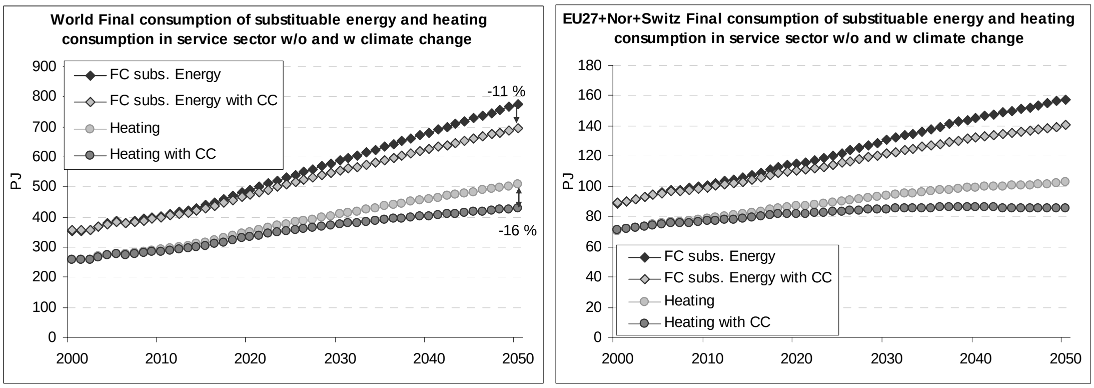
4.1.2.2 Results

The increase in temperature clearly curtails the heating demand. A comparison of the heating demand in the residential sector, with and without climate change impacts, shows a gap which widens in time to -17 % by 2050 at world level and to -18 % for the EU27 level. This shrinkage of heating demand translates into a reduction of the substitutable energy demand by -5 % at world level and -11 % in the EU27+2 level by 2050. The results in the service sector are comparable.



Source: POLES ADAM, Reference scenario

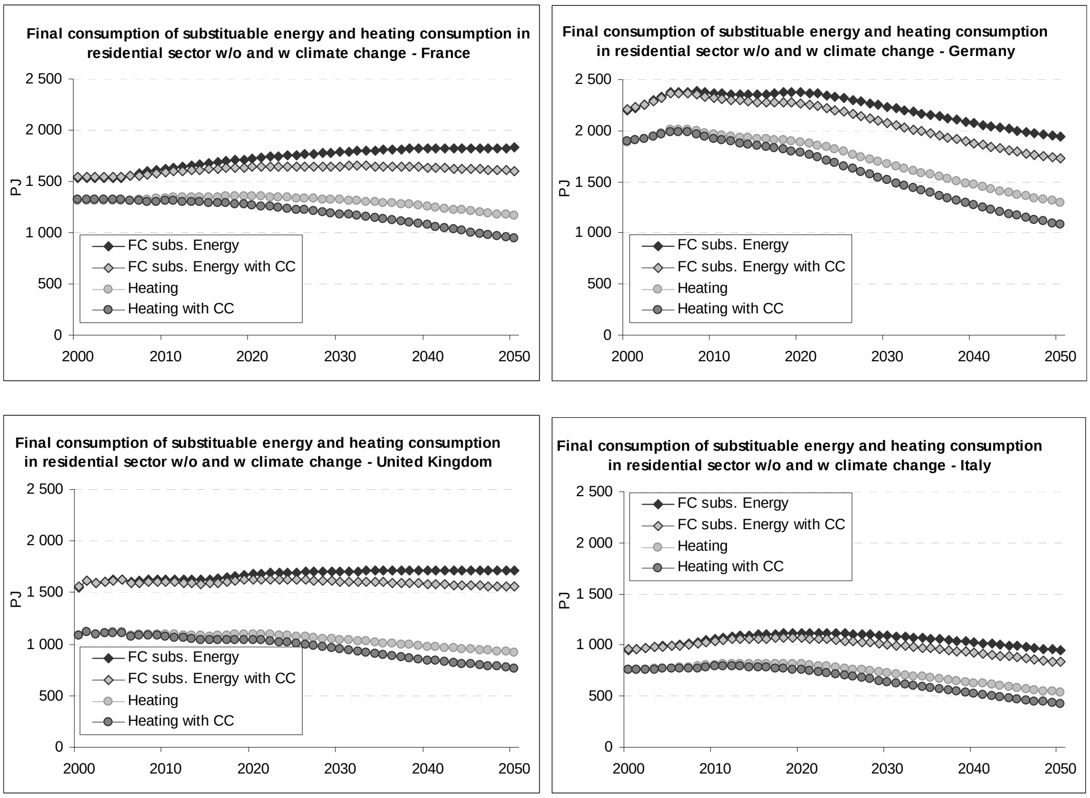
Figure 4-6: Final consumption of substitutable energy and heating consumption in the residential sector without and with climate change



Source: POLES ADAM, Reference scenario

Figure 4-7: Final consumption of substitutable energy and heating consumption in the service sector without and with climate change

Some examples of the impact of climate change on the heating and substitutable consumption in the residential sector at country level are presented in the following figure.



Source: POLES ADAM, Reference scenario

Figure 4-8: Final consumption of substitutable energy and heating consumption in the residential sector without and with climate change

4.1.2.3 Modelling the impacts of climate change on cooling demand

The method proposed to model the impact of climate change on residential cooling demand is based on the paper by McNeil and Letschert. We model the impact in two steps, firstly modelling air conditioning installation rates and then modelling the average baseline unit energy consumption (UEC).

Step 1: Modelling air conditioning installation

The air-conditioning equipment rate (ACER) is the multiplication of the climate maximum saturation rate (CMAX) by the air-conditioning availability (AVRES). Climate maximum saturation depends on the cooling degree days (CDD). For example, for the USA the climate maximum saturation (**CMAX)** can be calculated with the following equation:

$$\mathbf{CMAX = 1 - 0.949 * e^{(-0.00187 * CDD)}}$$

Residential air conditioning availability (**AVRES)** is dependent on revenues following a logistic S-curve: $\mathbf{AVRES = 1 / (1+ e^{(3.77610543)} * e^{(-0.22537608*GDPPOP)})}$ (6)

Then saturation is: $\mathbf{ACER = CMAX * AVRES}$

Step 2: Modelling unit energy consumption of residential dwellings (by dwelling)

The air-conditioning unit energy consumption (**ACUEC)** depends on cooling degree days, but there is a significant dependence on income as well. The following equation was refitted with POLES data:

$$\mathbf{ACUEC=CDD*(a * \ln(GDPPOP) + b)}$$

The equation is proposed in the paper by Morna Isaac and Detlef Van Vuuren, which is derived from McNeil. The logarithm takes into account saturation for high income levels.

$$\mathbf{ACUEC_{(t)} = ACUEC_{(t-1)} * \frac{CDD_{(t)}}{CDD_{(t-1)}} * \frac{(a * \ln(GDPPOP_{(t)}) + b)}{(a * \ln(GDPPOP_{(t-1)}) + b)}}$$

Where : $a = 7.2651*10^{-0.8}$, $b = 8.7398 * 10^{-0.5}$

Finally, the air conditioning electricity consumption with climate change impact (**FCCELRESC**) is calculated as production of climate maximum saturation (**CMAX),** residential air conditioning availability (**AVRES**)**,** the air-conditioning unit energy consumption (**ACUEC)** and the number of dwellings (**DWL**):

$$\mathbf{FCCELRESC_{[ALLC]} = CMAX_{[ALLC]} * AVRES_{[ALLC]} * ACUEC_{[ALLC]} * DWL_{[ALLC]}}$$

And the total captive electricity including the air conditioning:

$$\mathbf{FCCELRESTOT_{[ALLC]} = FCCELRES_{[ALLC]} - FCCELRESC_{[ALLC]}2000 + FCCELRESC_{[ALLC]}}$$

4.1.2.4 Data

The cooling degree days (**CDD**) data come from Timer/IMAGE, for 2°C scenario (771 ppmv in 2050a, +3.7°C since pre-industrial ages). The air conditioner saturation data and the unit energy consumption data come from the paper by McNeil and Letschert. The GDP per capita and the dwellings come from POLES: GDPPOP, DWL.

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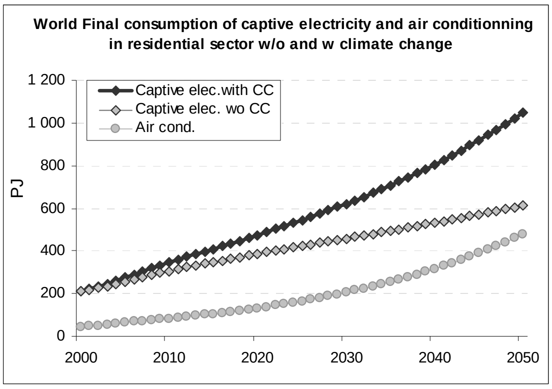
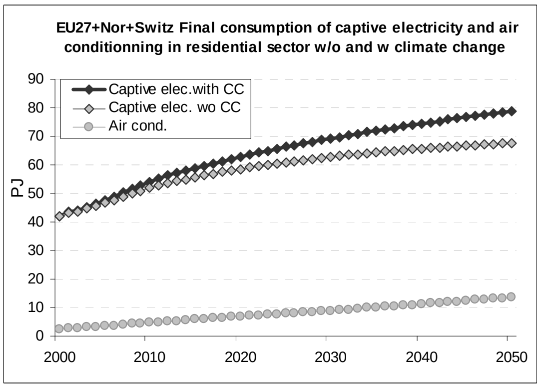
6 Model refitted with POLES data. $R2 = 0.66$.

4.1.2.5 Results





Source: POLES ADAM, Reference scenario

Figure 4-9: World and EU27+NOR+SWITZ final consumption for captive electricity and air conditioning in the residential sector

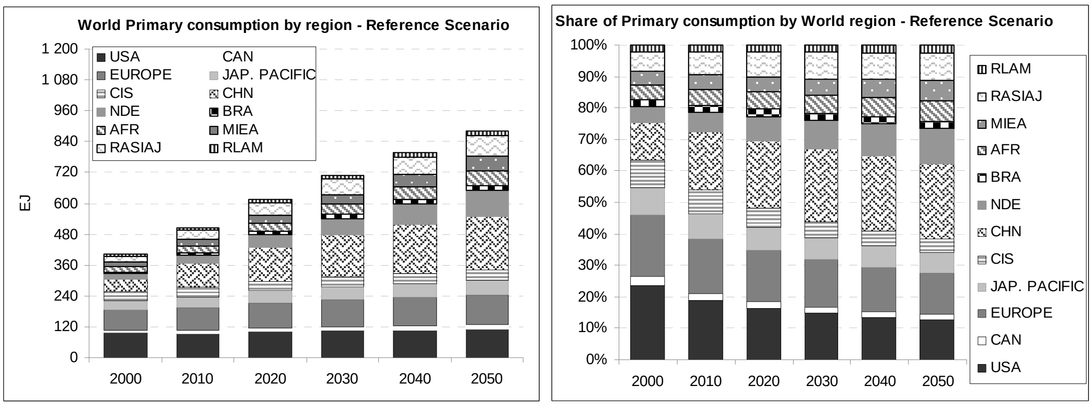
The net effect of climate change on global energy use and emissions is relatively small, as the increases in cooling are compensated for by the decreases in heating. However, impacts on heating and cooling individually are considerable in this scenario, with heating energy demand decreasing by 17 % worldwide by 2050 as a result of climate change, and air conditioning energy demand increasing by 72 %.

4.2 Energy balances and emission profiles in the 2°C projections

4.2.1 Primary energy balance

World GDP quadruples between now and 2050, in spite of relatively lower economic growth rates towards the end of the period. The energy intensity of the world GDP in 2050 falls to about half of the 2000 value due to structural change, autonomous efficiency improvements and higher prices. Consequently, world energy consumption roughly doubles from 414 EJ today to about 965 EJ in 2050.

The 1.6 %/year increase in world energy consumption to 2050 appears low, but the cumulative consequences are large, particularly at regional level. By 2050, the energy consumption of today's industrialised countries (including the CIS countries) increases by a factor of 1.3. In the developing world, consumption increases by a factor of 3.7. Shortly after 2020, the consumption of the developing countries exceeds that of the present industrialised countries (Figure 4-10). The role of developed countries and that of the European region in the world primary energy consumption is estimated to decrease during this period (respectively from 62 % to 38 % and from 19 % to 13 %).

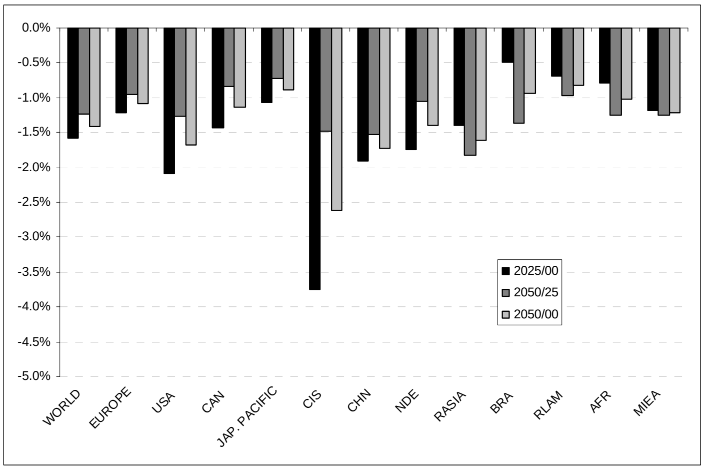


Source: POLES ADAM, Reference scenario[7]

Figure 4-10: World primary energy consumption in the Reference case, by region

The world energy system that results from this analysis reveals the significant structural changes that are needed to accommodate the constraints on fossil fuel resources. The primary energy consumption in Europe increases moderately over the period, from 78 EJ today, to only 104 EJ in 2050 (Figure 4-12). This is one of the lowest growth rates in the world. This behaviour appears clearly in the energy intensity of GDP, which falls throughout the period (-1.4 % in the world level).

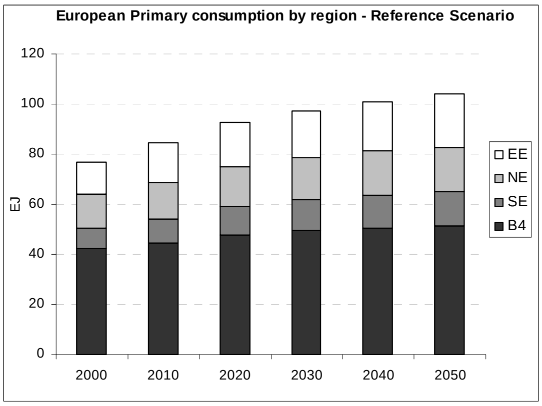
7 Where: RLAM- Rest of Latin America, RASIAJ-Rest of Asia, MIEA- Middle East, AFR-Africa, BRA-Brasil, NDE-Inde, CHN-China, CIS-Countries of the Indipendent States, JAP.PACIFIK – Japan & Pacific, EUROPE, CAN-Canada, USA-United States of America.



Source: POLES ADAM, Reference Sc.

Figure 4-11: Growth rates of the energy intensity of GDP by region of the world – Reference Scenario

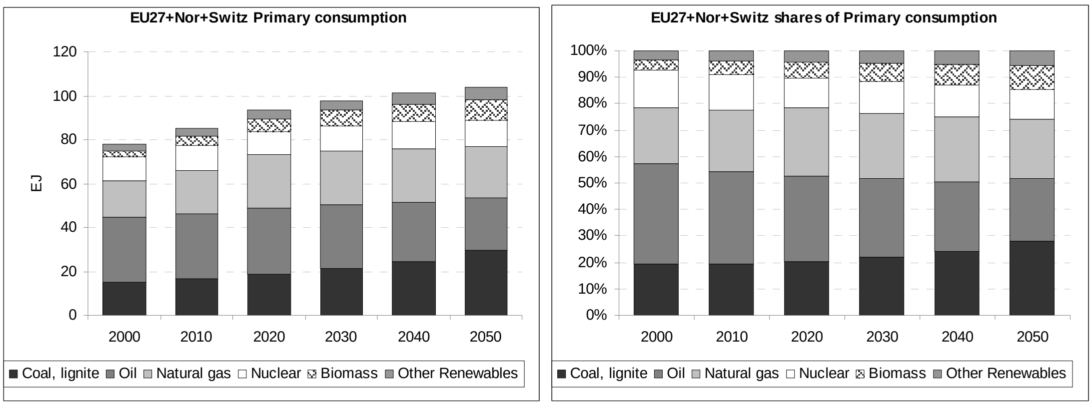
The primary consumption of the Big Four countries increases slightly from 42 EJ currently to 51 EJ by 2050. However, the share of these countries in the total primary consumption of Europe decreases steadily from 55 % to 47 in 2050.



Source: POLES ADAM, Reference Sc.

Figure 4-12: EU27+Nor+Switz primary energy consumption, by country and region

The contribution of fossil energy sources decreases from 80 % at the beginning of the century to 76 % by 2050. The consumption of oil and gas is restricted by high prices, in particular after 2020. By 2030, the consumption of oil and gas in Europe is less than in 2000. During the period, coal use more than doubles, providing slightly less than 30 EJ by 2050. Compared to the current 15 EJ, the figure is impressive. It reflects the relative abundance of coal and the resulting price advantage in the long term. Renewables increase steadily over the period, representing 15 % of primary consumption by 2050. The contribution of nuclear power is expected to diminish, from 10.5 EJ today to 12 EJ by 2050.



Source: POLES ADAM, Reference Sc.

Figure 4-13: EU27+Nor+Switz primary energy consumption

These trends have a clear impact on the energy self-sufficiency level of Europe:

1. The ratio of primary production to primary consumption is currently 53 %.
2. This ratio falls to 46 % between 2025 and 2050 because of falling production in the North Sea, despite the modest increase in demand.

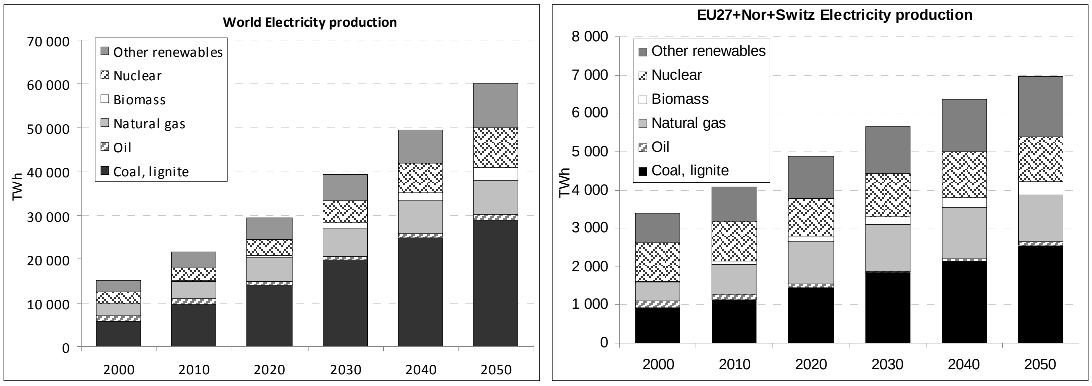
Table 4-5: Europe energy self-sufficiency ratio

	2000	2025	2050
Primary Production (Mtoe)	936	1022	1073
Primary Consumption (Mtoe)	1750	2139	2328
P. prod/P. cons (%)	53%	48%	46%

Source: POLES ADAM, Reference Sc.

4.2.2 The development of electricity generation

The generation of electricity, worldwide, increases nearly four-fold, from 15 200 TWh/year today, to 60 100 TWh/year by 2050 (Figure 4-14).



Source: POLES ADAM, Reference Sc.

Figure 4-14: World and EU27+Nor+Switz electricity production

In the EU27+2, electricity production more than doubles during the first half of the century. The evolution at country level is estimated to be similar for the Big Four and still faster for other European countries. For example, in southern European countries electricity generation is multiplied by 4 in 5 decades.

Table 4-6: Electricity generation by country in Europe (TWh)

								Annual % change		
	1990	2000	2005	2010	2020	2030	2050	2000/20	20/50	50/100
Austria	50	62	63	67	82	97	118	1.5%	1.2%	0.3%
Baltic States	34	24	33	45	54	62	77	4.1%	1.2%	0.3%
Belgium & Luxemburg	72	85	82	97	119	146	190	1.7%	1.6%	0.4%
Bulgaria	42	40	43	50	60	67	78	2.1%	0.9%	0.4%
Cyprus, Malta and Slovenia	16	19	26	28	35	41	51	3.1%	1.3%	0.4%
Czech Republic	63	73	80	94	113	128	156	2.2%	1.1%	0.3%
Denmark	26	36	48	52	62	72	87	2.8%	1.1%	0.3%
Finland	54	70	73	83	108	128	165	2.2%	1.4%	0.2%
France	421	541	568	630	759	878	1072	1.7%	1.2%	0.1%
Germany	550	567	610	655	766	862	1005	1.5%	0.9%	0.3%
Greece	35	52	61	72	93	109	134	2.9%	1.2%	0.4%
Hungary	28	35	38	45	55	67	92	2.2%	1.8%	0.1%
Ireland	15	24	25	31	38	48	65	2.3%	1.8%	0.2%
Italy	217	233	287	320	368	417	467	2.3%	0.8%	0.0%
Netherlands	72	89	98	108	140	177	229	2.3%	1.6%	0.3%
Norway and Switzerland	159	214	202	223	257	292	334	0.9%	0.9%	0.5%
Poland	136	145	153	184	234	278	393	2.4%	1.7%	0.0%
Portugal	29	44	51	60	75	90	113	2.8%	1.4%	0.3%
Romania	64	52	56	63	81	97	134	2.3%	1.7%	0.4%
Slovakia	24	31	31	38	45	52	68	1.9%	1.4%	0.6%
Spain	152	221	283	321	411	486	621	3.2%	1.4%	0.5%
Sweden	146	145	162	166	182	190	218	1.1%	0.6%	0.1%
United Kingdom	320	377	394	422	489	595	790	1.3%	1.6%	0.2%
Rceu	61	64	76	109	145	175	239	4.2%	1.7%	0.5%
Turkey	58	125	155	207	352	550	963	5.3%	3.4%	1.7%
EU27+Nor+Switz	2571	3178	3469	3856	4625	5380	6656	1.9%	1.2%	0.0%
Europe	2845	3367	3699	4172	5123	6104	7859	2.1%	1.4%	0.0%
B4	1507	1719	1859	2027	2382	2752	3334	1.6%	1.1%	0.2%
SE	231	336	421	482	614	726	920	3.1%	1.4%	0.5%
NE	544	662	691	761	907	1053	1288	1.6%	1.2%	0.3%
EE	504	525	573	695	868	1024	1354	2.5%	1.5%	0.3%

Source: POLES ADAM, Reference Sc.

The share of thermal generation increases until 2030-2040 (up to 69 % at the world level and 61 % for EU27+2) because other sources cannot match the growth in demand. This is a significant structural change for a Reference case. The role of thermal generation varies from country to country. Currently, in the eastern and southern European countries, 65 % and 63 % respectively of electricity generation is provided by thermal power plants. This contribution is expected to be relatively stable during the entire period, decreasing slightly at the end of the period (respectively, to respectively 66 % and 70 %). The role of thermal generation advances in the Big Four countries and in the northern European countries, respectively, from 51 and 33 % currently to 64 and 49 % by 2050.

Table 4-7: The share of thermal generation in total electricity generation

	2000	2010	2020	2020	2030	2050
EU27+Nor+Switz	51%	55%	55%	61%	61%	63%
Europe	52%	57%	57%	61%	61%	63%
B4	51%	57%	57%	63%	62%	64%
SE	63%	66%	66%	63%	66%	70%
NE	33%	38%	38%	46%	49%	49%
EE	65%	66%	66%	65%	65%	66%

Source: POLES ADAM, Reference Sc.

Within the thermal generation sector, advanced technologies will progressively gain the lion's share. In 2050 in the EU27+2, less than 39 % of coal-based power generation is from advanced coal technologies and 22 % of gas-based electricity is from combined cycle or co-generation. Oil almost disappears from the electricity sector (Table 4-8).

Table 4-8: EU27+Nor+Switz electricity generation by technology

	2000	2010	2020	2030	2040	2050	Annual % change 2020/00	50/20	50/00
Electricity Production (TWh)	3178	3856	4625	5380	6073	6656	1.9%	1.2%	1.5%
Thermal, of which :	1617	2139	2799	3289	3785	4185	2.8%	1.3%	1.9%
Coal, lignite	925	1138	1463	1823	2143	2563	2.3%	1.9%	2.1%
of which advanced coal	0	46	557	1137	1495	1625	n.a	3.6%	n.a
Gas	507	792	1122	1206	1315	1214	4.1%	0.3%	1.8%
of which combined cycle	278	392	691	777	813	668	4.7%	-0.1%	1.8%
of which cogeneration (industry)	50	106	146	182	225	268	5.6%	2.0%	3.4%
Oil	181	127	65	49	54	61	-5.0%	-0.2%	-2.2%
Biomass	43	82	149	211	272	347	6.5%	2.9%	4.3%
Nuclear	972	1003	925	1044	1099	1097	-0.2%	0.6%	0.2%
of which new design	0	0	0	0	50	167	n.a	n.a	n.a
Hydro (large)	520	494	502	509	514	518	-0.2%	0.1%	0.0%
Hydro (small)	45	53	57	58	58	59	1.1%	0.1%	0.5%
Wind	22	159	305	405	475	543	14.0%	1.9%	6.6%
Solar	0	7	37	73	137	235	n.a	6.4%	n.a

Source: POLES ADAM, Reference Sc.

World generation from renewable resources grows strongly, being multiplied by 5 in 2050. The development of renewable electricity in the EU27+2 almost meets the EU's target of 20 % of total power generation by 2020. This share is maintained and even increases farther in the future to 23 % by 2050.

The contribution of renewables in the total electricity generation by country is projected to be more important in northern European countries (47 % currently, 42 % by 2020, 45 % by 2050). In the Big Four countries it seems that without climate policies the role of renewables remains at a relatively low level: 17 % by 2020, 21 % by 2050. Renewables in other European countries are situated in between the former two groups of countries[8]: 21 % by 2020 and respectively 19 and 26 % by 2050 for eastern and southern European countries.

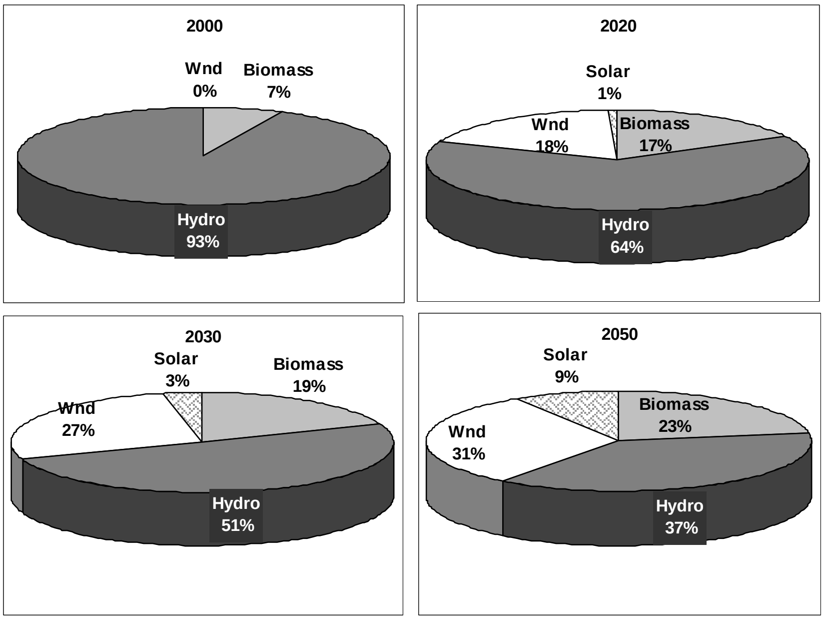
Table 4-9: The share of renewable electricity generation by country

								Annual % change		
	1990	2000	2005	2010	2020	2030	2050	2020/00	50/20	50/00
Austria	65%	73%	67%	77%	78%	82%	81%	0.3%	0.1%	0.2%
Baltic States	9%	15%	13%	9%	10%	11%	15%	-1.8%	1.4%	0.1%
Belgium & Luxemburg	2%	4%	6%	8%	13%	17%	26%	5.7%	2.4%	3.7%
Bulgaria	4%	7%	11%	9%	10%	13%	20%	1.7%	2.2%	2.0%
Cyprus, Malta and Slovenia	21%	21%	16%	18%	19%	21%	28%	-0.4%	1.3%	0.6%
Czech Republic	2%	4%	5%	5%	8%	8%	10%	3.6%	0.6%	1.8%
Denmark	2%	17%	22%	21%	23%	26%	30%	1.6%	0.9%	1.2%
Finland	20%	34%	32%	26%	26%	30%	41%	-1.3%	1.5%	0.4%
France	14%	14%	11%	13%	16%	17%	21%	0.6%	1.0%	0.8%
Germany	4%	7%	12%	13%	16%	17%	19%	3.8%	0.7%	1.9%
Greece	6%	9%	12%	11%	13%	14%	21%	2.0%	1.6%	1.7%
Hungary	1%	1%	5%	6%	8%	10%	15%	12.2%	2.0%	5.9%
Ireland	7%	6%	9%	10%	14%	18%	27%	4.1%	2.2%	3.0%
Italy	18%	23%	18%	22%	28%	28%	31%	1.0%	0.3%	0.6%
Netherlands	0%	5%	9%	10%	10%	11%	17%	3.7%	1.8%	2.6%
Norway and Switzerland	99%	87%	88%	78%	71%	66%	67%	-1.0%	-0.2%	-0.5%
Poland	2%	3%	4%	6%	8%	9%	15%	4.9%	2.2%	3.3%
Portugal	33%	31%	18%	30%	33%	32%	34%	0.4%	0.1%	0.2%
Romania	18%	29%	36%	27%	24%	23%	24%	-0.9%	0.0%	-0.3%
Slovakia	10%	16%	15%	15%	16%	17%	19%	0.1%	0.5%	0.3%
Spain	17%	17%	17%	22%	20%	18%	15%	0.7%	-1.0%	-0.3%
Sweden	50%	57%	51%	52%	65%	70%	72%	0.6%	0.3%	0.5%
United Kingdom	2%	3%	5%	9%	14%	16%	16%	7.3%	0.4%	3.1%
Rceu	38%	45%	42%	31%	33%	35%	38%	-1.5%	0.4%	-0.3%
Turkey	40%	25%	26%	22%	19%	19%	22%	-1.2%	0.4%	-0.3%
EU27+Nor+Switz	17%	20%	19%	21%	23%	23%	26%	0.7%	0.4%	0.5%
Europe	18%	21%	20%	21%	23%	23%	26%	0.5%	0.4%	0.4%
B4	8%	11%	11%	14%	17%	19%	21%	2.4%	0.6%	1.3%
SE	18%	18%	16%	21%	21%	19%	19%	0.7%	-0.3%	0.1%
NE	45%	47%	45%	41%	42%	41%	45%	-0.6%	0.3%	-0.1%
EE	16%	20%	21%	19%	21%	23%	26%	0.2%	0.7%	0.5%

Source: POLES ADAM, Reference Sc.

The structure of the renewable electricity mix varies over time. In the case of the EU27+2, the share of hydro decreases from 90 % by 2000, to 55 % by 2020 and to 30 % by 2050. Biomass, wind and solar energy will increase their involvement throughout the decades, emerging with respectively 23 %, 31 % and 9 % at the end of the period.

[8] Northern European countries and Big Four countries.



Source: POLES ADAM, Reference Sc.

Figure 4-15: EU27+Nor+Switz share of the different sources in the total renewable generation

The absolute contribution and the share of nuclear electricity both decrease until 2020, as some second-generation plants are retired. World electricity generation in nuclear plants revives after that date, with the rapid introduction of third- and fourth-generation plants increasing four times by 2050. In the EU27+2, the contribution of nuclear energy remains relatively stable. However, 12 % of electricity in the EU27+2 will come from nuclear energy by 2050.

In Europe, France, the United Kingdom and Turkey play a major role in nuclear generation. While nuclear generation in France decreases after 2030, it will increase in the United Kingdom and Turkey.

Table 4-10: Nuclear electricity generation by European country

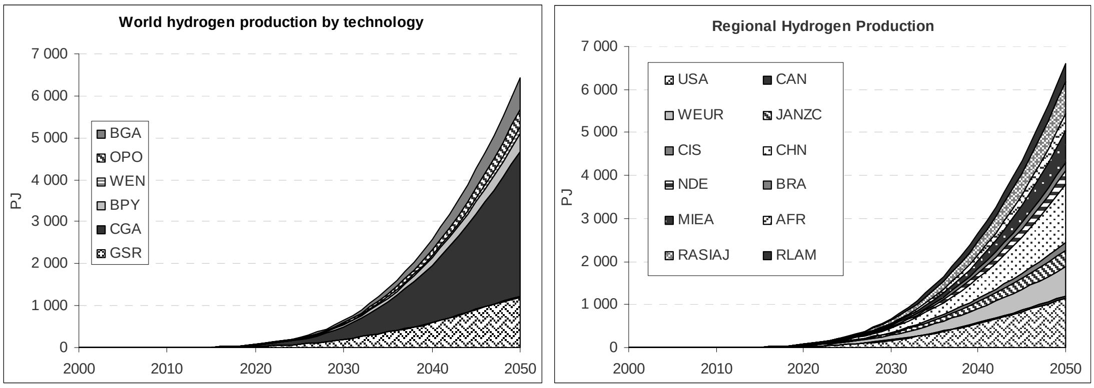
	2000	2010	2020	2030	2050	Annual % change 2020/00	50/20	50/00
Austria	0	0	0	0	0	59.1%	5.1%	24.1%
Baltic States	8	19	20	15	13	4.3%	-1.5%	0.8%
Belgium & Luxemburg	48	43	33	26	16	-1.8%	-2.5%	-2.2%
Bulgaria	18	17	17	16	14	-0.3%	-0.5%	-0.5%
Cyprus, Malta and Slovenia	5	7	10	12	10	3.7%	0.0%	1.5%
Czech Republic	14	33	33	29	26	4.6%	-0.8%	1.3%
Denmark	0	0	0	1	11	81.5%	21.8%	42.9%
Finland	23	35	36	37	33	2.4%	-0.3%	0.8%
France	415	439	427	483	390	0.1%	-0.3%	-0.1%
Germany	170	128	9	0	0	-13.6%	n.a	n.a
Greece	0	0	7	15	18	138.7%	n.a	44.2%
Hungary	14	17	19	18	18	1.4%	-0.2%	0.4%
Ireland	0	0	0	0	0	74.1%	-2.5%	23.0%
Italy	0	0	0	2	30	n.a	n.a	45.7%
Netherlands	4	13	25	46	65	9.7%	3.2%	5.8%
Norway and Switzerland	26	36	56	71	79	3.8%	1.2%	2.2%
Poland	0	1	13	43	72	n.a	5.8%	48.3%
Portugal	0	0	7	15	19	n.a	3.3%	44.3%
Romania	5	6	9	14	16	2.5%	1.9%	2.1%
Slovakia	17	19	16	13	11	-0.2%	-1.3%	-0.8%
Spain	62	59	86	79	73	1.6%	-0.6%	0.3%
Sweden	57	64	22	0	0	-4.7%	n.a	n.a
United Kingdom	85	69	80	109	185	-0.3%	2.8%	1.6%
Rceu	0	5	22	31	33	152.7%	1.3%	46.0%
Turkey	0	0	29	83	145	155.9%	5.5%	50.4%
EU27+Nor+Switz	972	1003	925	1044	1097	-0.2%	0.6%	0.2%
Europe	972	1007	977	1158	1274	0.0%	0.9%	0.5%
B4	670	636	516	595	604	-1.3%	0.5%	-0.2%
SE	67	66	110	120	119	2.5%	0.3%	1.2%
NE	158	190	173	181	204	0.4%	0.6%	0.5%
EE	76	115	149	179	202	3.4%	1.0%	2.0%

Source: POLES ADAM, Reference Sc.

4.2.3 Hydrogen production

In the Reference case, the development of hydrogen production remains limited at the world level (6.6 PJ in 2050). In 2050, it represents only 1.2 % of total final energy consumption. In the EU27+2 the contribution of hydrogen is even lower (it represents only 0.8 % of total final energy consumption in 2050.

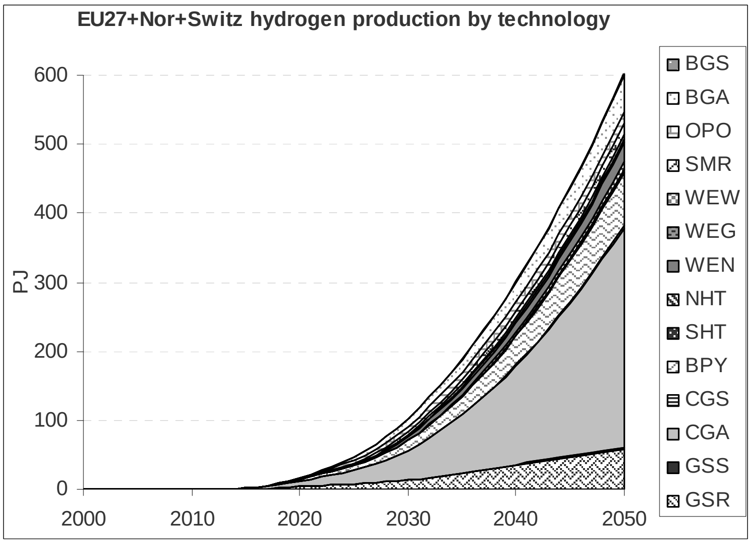
As illustrated in Figure 4-16, hydrogen production comes mostly from coal. The production from steam reforming of natural gas is limited by increasing gas prices and is more costly than hydrogen from coal gasification. World hydrogen production has a relatively balanced profile across regions.



Source: POLES ADAM, Reference Sc[9].

Figure 4-16: Hydrogen energy production by technology and by region

The amount of hydrogen production for energy purposes in Europe is very limited until 2030. Thereafter it begins to penetrate the market and by 2050, total production is of 604 PJ. This is equivalent to 3 % of total final consumption of electricity (Figure 4-17).

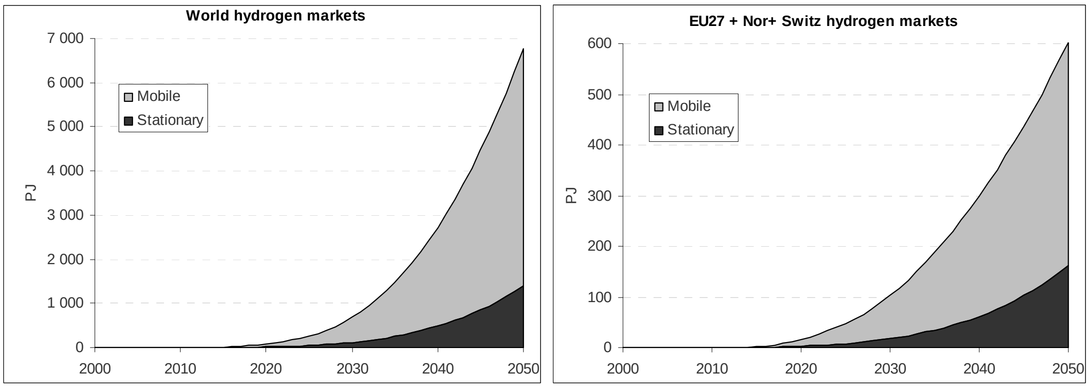


Source: POLES ADAM, Reference Sc.

Figure 4-17: Hydrogen production in EU27+Nor+Switz

Nearly two thirds of hydrogen produced at the world level is used for mobility purposes in the transport market, which represents 79 % of the total by 2050. In the EU27+2 countries this figure represents 74 % of the total hydrogen used in the transport sector by 2050.

9 Where: RLAM- Rest of Latin America, RASIAJ-Rest of Asia, MIEA- Middle East, AFR-Africa, BRA-Brasil, NDE-Inde, CHN-China, CIS-Countries of the Indipendent States, JAP.PACIFIK – Japan & Pacific, EUROPE, CAN-Canada, USA-United States of America.



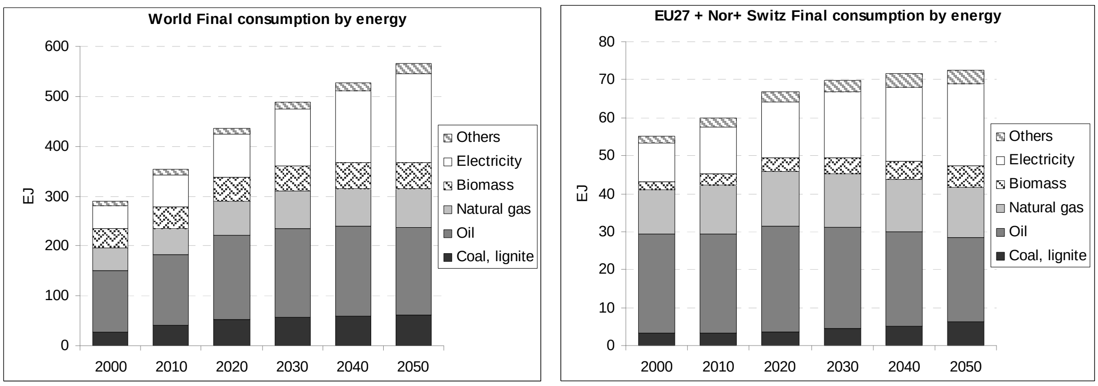
Source: POLES ADAM, Reference Sc.

Figure 4-18: World and EU27+Nor+Switz hydrogen markets

4.2.4 Trends in final energy demand

Expected world final energy demand almost doubles by 2050, but then increases more slowly. Final electricity demand increases significantly faster, at a rate of more than 2 %/year which means an increase from 45 EJ in 2000 to 178 EJ in 2050.

The final consumption of energy in the EU27+2, increases during the period at an average rate of 0.55 %/year. This tendency is confirmed in all European countries, however, the speed is lower in the Big Four and northern countries and faster in the rest of the Europe.



Source: POLES ADAM, Reference Sc.

Figure 4-19: World and EU 27+Nor+Switz final energy consumption by energy

Table 4-11: Final energy consumption by European country

	2000	2010	2020	2030	2050	Annual % change 2020/00	50/20	50/00
Austria	1.0	1.2	1.3	1.4	1.3	1.3%	0.0%	0.5%
Baltic States	0.4	0.6	0.7	0.8	0.8	2.5%	0.5%	1.3%
Belgium & Luxemburg	2.1	2.1	2.4	2.5	2.5	0.6%	0.2%	0.4%
Bulgaria	0.4	0.5	0.7	0.7	0.7	2.3%	0.3%	1.1%
Cyprus, Malta and Slovenia	0.3	0.4	0.4	0.4	0.5	1.4%	0.5%	0.9%
Czech Republic	1.1	1.3	1.5	1.6	1.7	1.6%	0.4%	0.9%
Denmark	0.6	0.7	0.8	0.8	0.8	1.1%	0.2%	0.5%
Finland	1.0	1.2	1.4	1.5	1.6	1.5%	0.6%	1.0%
France	7.1	7.6	8.6	9.3	10.1	0.9%	0.6%	0.7%
Germany	10.3	10.7	11.7	11.9	11.8	0.6%	0.0%	0.3%
Greece	0.8	0.9	1.1	1.1	1.2	1.4%	0.5%	0.9%
Hungary	0.7	0.9	1.0	1.1	1.2	1.6%	0.5%	1.0%
Ireland	0.5	0.6	0.6	0.6	0.6	1.4%	0.1%	0.6%
Italy	5.6	6.0	6.4	6.4	5.9	0.7%	-0.3%	0.1%
Netherlands	2.5	2.8	3.1	3.3	3.4	1.1%	0.3%	0.6%
Norway and Switzerland	1.8	1.9	2.1	2.3	2.4	0.8%	0.4%	0.6%
Poland	2.5	2.8	3.3	3.5	4.0	1.3%	0.6%	0.9%
Portugal	0.8	0.9	1.0	1.1	1.1	0.7%	0.5%	0.6%
Romania	1.0	1.3	1.5	1.5	1.6	1.9%	0.3%	1.0%
Slovakia	0.5	0.6	0.6	0.7	0.7	1.2%	0.3%	0.6%
Spain	3.8	4.6	5.5	5.9	6.2	1.9%	0.4%	1.0%
Sweden	1.5	1.5	1.6	1.7	1.8	0.4%	0.4%	0.4%
United Kingdom	6.8	6.9	7.4	7.6	8.0	0.4%	0.2%	0.3%
Rceu	0.7	1.3	1.6	1.8	2.1	3.9%	1.0%	2.2%
Turkey	2.4	3.3	5.0	6.2	8.1	3.7%	1.6%	2.5%
EU27+Nor+Switz	53.3	58.0	64.7	67.5	70.2	1.0%	0.3%	0.6%
Europe	56.4	62.5	71.2	75.5	80.4	1.2%	0.4%	0.7%
B4	29.8	31.2	34.1	35.2	35.8	0.7%	0.2%	0.4%
SE	5.7	6.8	8.0	8.5	9.1	1.7%	0.4%	0.9%
NE	10.1	10.7	12.1	12.7	13.3	0.9%	0.3%	0.6%
EE	8.4	10.5	12.1	12.9	14.1	1.8%	0.5%	1.0%

Source: POLES ADAM, Reference Sc.

EU27+2 final electricity demand increases at a faster pace than final energy consumption, of more than 0.9 %/year, but much more slowly than the world average for electricity. At the country level, since the increase of electricity demand in the southern and eastern European countries is most rapid, the role of the Big 4 and northern countries decreases from 73 % currently to 61 % by 2050.

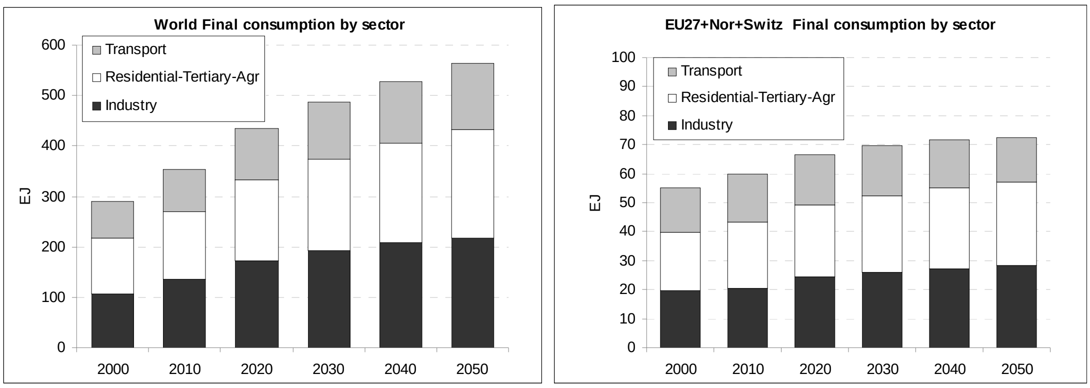
Table 4-12: Final electricity consumption by European country

						Annual % change		
	2000	2010	2020	2030	2050	2020/00	50/20	50/00
Austria	0.2	0.2	0.3	0.3	0.4	2.0%	1.2%	1.5%
Baltic States	0.1	0.1	0.1	0.2	0.2	4.3%	1.3%	2.5%
Belgium & Luxemburg	0.3	0.4	0.4	0.5	0.7	1.8%	1.4%	1.6%
Bulgaria	0.1	0.1	0.1	0.2	0.2	2.3%	1.0%	1.5%
Cyprus, Malta and Slovenia	0.1	0.1	0.1	0.1	0.2	2.8%	1.4%	1.9%
Czech Republic	0.2	0.2	0.3	0.3	0.4	2.5%	1.3%	1.8%
Denmark	0.1	0.1	0.2	0.2	0.2	1.7%	1.3%	1.5%
Finland	0.3	0.3	0.4	0.5	0.6	2.1%	1.3%	1.6%
France	1.4	1.7	2.1	2.5	3.1	2.1%	1.3%	1.6%
Germany	1.8	2.0	2.3	2.6	3.1	1.4%	1.0%	1.1%
Greece	0.2	0.2	0.3	0.3	0.4	2.9%	1.3%	1.9%
Hungary	0.1	0.1	0.2	0.2	0.3	2.1%	1.7%	1.9%
Ireland	0.1	0.1	0.1	0.2	0.2	2.8%	1.8%	2.2%
Italy	1.0	1.2	1.3	1.5	1.7	1.6%	0.8%	1.1%
Netherlands	0.4	0.4	0.5	0.6	0.8	1.8%	1.5%	1.6%
Norway and Switzerland	0.6	0.7	0.8	0.9	1.1	1.5%	0.9%	1.1%
Poland	0.3	0.4	0.6	0.7	1.0	2.4%	1.9%	2.1%
Portugal	0.1	0.2	0.2	0.3	0.4	2.8%	1.4%	2.0%
Romania	0.1	0.2	0.2	0.3	0.4	2.7%	1.8%	2.2%
Slovakia	0.1	0.1	0.1	0.1	0.2	2.3%	1.5%	1.8%
Spain	0.7	1.0	1.3	1.5	1.9	3.1%	1.4%	2.1%
Sweden	0.5	0.5	0.5	0.6	0.7	0.8%	0.6%	0.7%
United Kingdom	1.2	1.3	1.5	1.9	2.5	1.3%	1.6%	1.5%
Rceu	0.2	0.3	0.4	0.5	0.7	3.9%	1.6%	2.5%
Turkey	0.3	0.6	1.1	1.7	3.0	5.8%	3.5%	4.4%
EU27+Nor+Switz	9.7	11.8	14.1	16.5	20.5	1.9%	1.3%	1.5%
Europe	10.2	12.7	15.6	18.6	24.2	2.1%	1.5%	1.7%
B4	5.3	6.2	7.3	8.5	10.4	1.6%	1.2%	1.3%
SE	1.0	1.5	1.9	2.2	2.9	3.0%	1.4%	2.1%
NE	2.2	2.5	3.0	3.5	4.3	1.6%	1.2%	1.3%
EE	1.4	1.8	2.3	2.8	3.7	2.7%	1.6%	2.0%

Source: POLES ADAM, Reference Sc.

In sectoral terms (Figure 4-20), the fastest increase in world final consumption is observed in the residential and service sector (1.2 %/year), followed by transport (0.8 %/year) and industry (0.6 %/year). Figure 4-20 reveals a long-term stabilisation of energy consumption in the transport sector at world level, while for the EU27+2 countries a slight slowdown is seen. This is an important change in the pattern of demand. In the past thirty years, the long-lasting decoupling of "energy services" from GDP has only been observed for stationary uses of fuels and only temporarily for transport, i.e. in the USA after the first oil shock and the introduction of the CAFE standards. There are several possible explanations for this new trend in transport, including: saturation in equipment and in the time budget for personal transport, significant oil price increases; the impact of more severe technological standards. In this respect, the Reference case again already includes significant structural change.

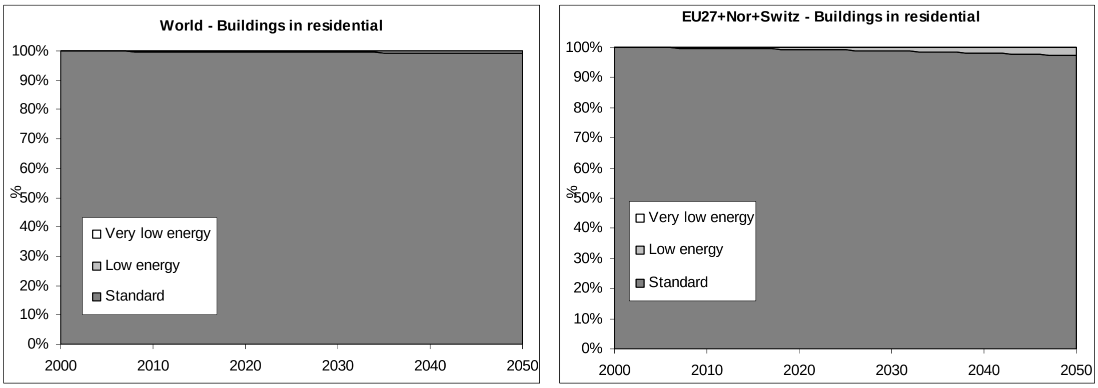
Changes in the transport sector suggest that the EU27+2 may have already entered a second phase of energy decoupling, with electricity remaining the only energy carrier or service for which demand continues to grow. The third and final phase of decoupling – that of electricity, if it ever happens – is not visible before the 2050 horizon.



Source: POLES ADAM, Reference Sc.

Figure 4-20: World and EU27+Nor+Switz final energy consumption by sector

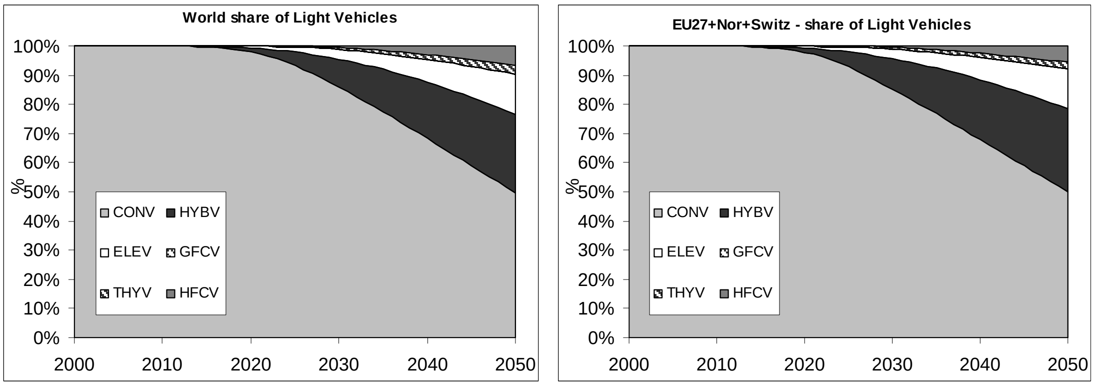
The version of the POLES model used in ADAM incorporates the diffusion of new low energy or very low energy buildings, which consume only one half or one quarter respectively of the rate in the average existing buildings in each region. The VLE building concept reflects current efforts in many countries to develop zero or even positive energy buildings, when associated with integrated solar PV panels. In the Reference case, while price increases allow for more energy efficiency in buildings, they are insufficient to overcome the building stock inertia and to trigger a significant development of low and very low energy buildings: in 2050 their world and EU27+2 market is only 1 % and 3 %.



Source: POLES ADAM, Reference Sc.

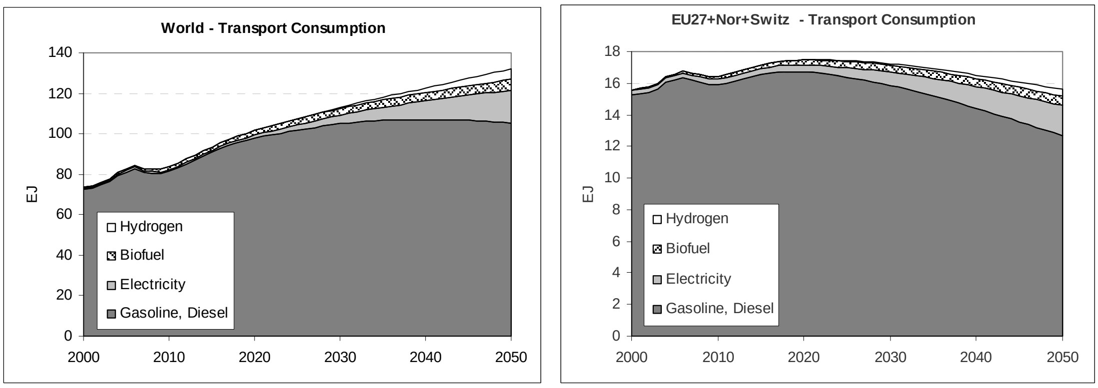
Figure 4-21: World and EU27+Nor+Switz buildings in residential

Similarly, in the transport sector, different types of technologies take into account the effort of many actors to develop cleaner cars. In that case, stock effects and inertias are lower and the impact of oil prices stronger, so that conventional cars steadily lose market shares and hybrid, electric, hydrogen ICE and hydrogen fuel cell technologies progressively increase their market share after 2020. In that way, while world transport consumption continues to expand, the role of electricity and hydrogen in transport fuels expands significantly. In the EU27+2 light vehicle consumption peak much earlier, during 2015-2035, and then decrease to 15 EJ by the end of the period.



Source: POLES ADAM Reference Sc.

Figure 4-22: World and EU27+Nor+Switz share of light vehicles



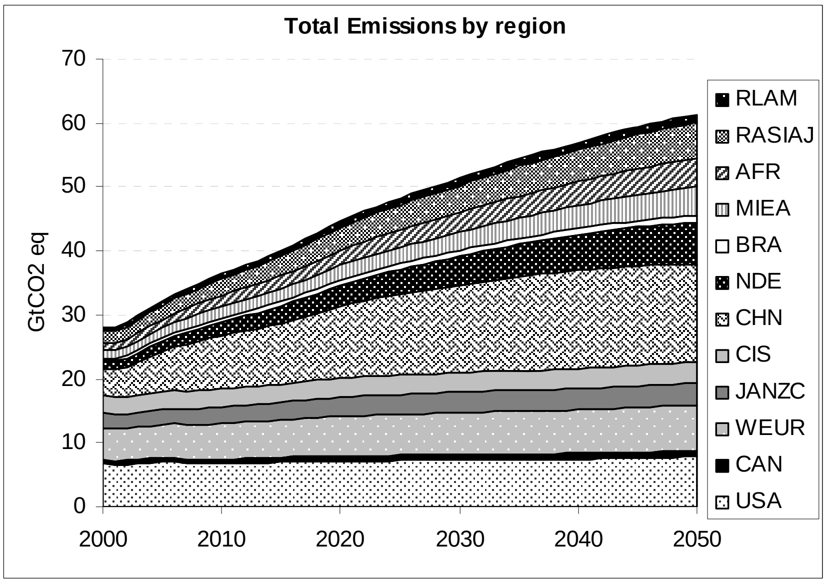
Source: POLES ADAM, Reference Sc.

Figure 4-23: World and EU27+Nor+Switz transport consumption

4.2.5 GHG emissions

World GHG emissions from energy and industrial activities double until 2050. The result is serious, because the trajectory would probably lead to a concentration of about 1000 ppmv CO_2e by the end of the century and therefore to a temperature increase of at least 3-4°C already in 2050. Energy and climate policies with limited ambitions will not solve the climate change problem. The combined effects of all structural and technological changes in the Reference case are that GHG emissions are 2.2 times greater in 2050 than in 2005.

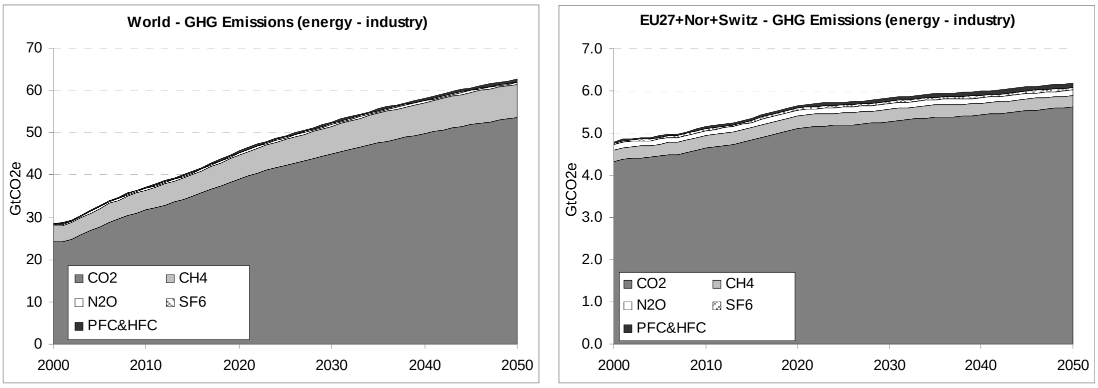
The GHG emissions of Annex B countries increase slowly from 15 $GtCO_2e$ in 2005, to 19 $GtCO_2e$ by 2050. The increase in non-Annex B regions is dramatic; emissions are 17 $GtCO_2e$ in 2005, but by 2050 the emissions from non-Annex B countries are up to 42 $GtCO_2e$ and amount to two thirds of the world total. This reflects the magnitude of energy needs in the developing world, which are only partly contained by price increases, and are also increasingly met by coal in a context of expensive oil and gas.



Source: POLES ADAM, Reference Sc.

Figure 4-24: World GHG emissions by region

As for Europe, the level of GHG emissions from energy and industrial activities peaks by 2050 at 5.9 $GtCO_2e$. This behaviour is a consequence of low population growth or even decrease in some regions, the high price of energy and also of the implementation of climate policies, even when they are moderate.



Source: POLES ADAM, Reference Sc.

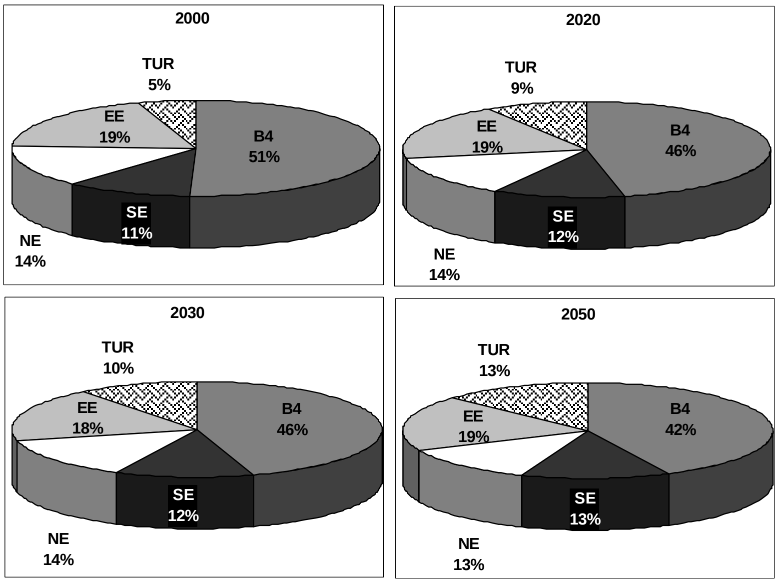
Figure 4-25: World and EU27+Nor+Switz - GHG emissions (energy – industry)

The evolution of CO_2 emissions by country in Europe is described in Table 4-13 that displays contrasting dynamics. The contribution of the Big Four and northern European countries in European CO_2 emissions decreases from 50 % and 14 % by 2005, to 42 % and 13 % by 2050. The role of eastern European countries remains relatively stable, while that of Turkey increases considerably from 5 % by 2005 to 13 % by 2050.

Table 4-13: CO_2 emissions by European country ($MtCO_2$)

						Annual % change		
	2000	2010	2020	2030	2050	2020/00	50/20	50/00
Austria	66	67	70	66	61	0.2%	-0.5%	-0.2%
Baltic States	29	39	49	56	65	2.5%	1.0%	1.6%
Belgium & Luxemburg	148	144	170	183	187	0.7%	0.3%	0.5%
Bulgaria	51	66	72	72	72	1.8%	0.0%	0.7%
Cyprus, Malta and Slovenia	31	38	39	38	43	1.1%	0.4%	0.7%
Czech Republic	117	126	138	146	159	0.8%	0.5%	0.6%
Denmark	54	66	71	72	64	1.3%	-0.3%	0.3%
Finland	67	68	74	79	88	0.5%	0.6%	0.6%
France	400	457	534	550	682	1.5%	0.8%	1.1%
Germany	837	864	1006	1022	1045	0.9%	0.1%	0.4%
Greece	88	101	110	115	119	1.1%	0.3%	0.6%
Hungary	51	61	71	79	91	1.7%	0.8%	1.2%
Ireland	46	52	57	59	59	1.1%	0.1%	0.5%
Italy	429	438	441	436	393	0.1%	-0.4%	-0.2%
Netherlands	180	187	205	211	213	0.6%	0.1%	0.3%
Norway and Switzerland	81	85	95	102	99	0.8%	0.1%	0.4%
Poland	327	341	350	331	368	0.3%	0.2%	0.2%
Portugal	62	59	67	72	80	0.4%	0.6%	0.5%
Romania	85	103	114	112	129	1.5%	0.4%	0.8%
Slovakia	37	46	51	55	62	1.6%	0.6%	1.0%
Spain	308	369	429	482	575	1.7%	1.0%	1.3%
Sweden	55	54	73	87	94	1.5%	0.8%	1.1%
United Kingdom	565	595	585	594	612	0.2%	0.1%	0.2%
Rceu	84	149	146	149	180	2.8%	0.7%	1.5%
Turkey	218	316	486	605	826	4.1%	1.8%	2.7%
EU27+Nor+Switz	4112	4425	4871	5016	5359	0.8%	0.3%	0.5%
Europe	4414	4891	5503	5770	6366	1.1%	0.5%	0.7%
B4	2231	2353	2567	2601	2731	0.7%	0.2%	0.4%
SE	489	567	645	706	817	1.4%	0.8%	1.0%
NE	630	656	745	791	805	0.8%	0.3%	0.5%
EE	847	998	1060	1067	1187	1.1%	0.4%	0.7%

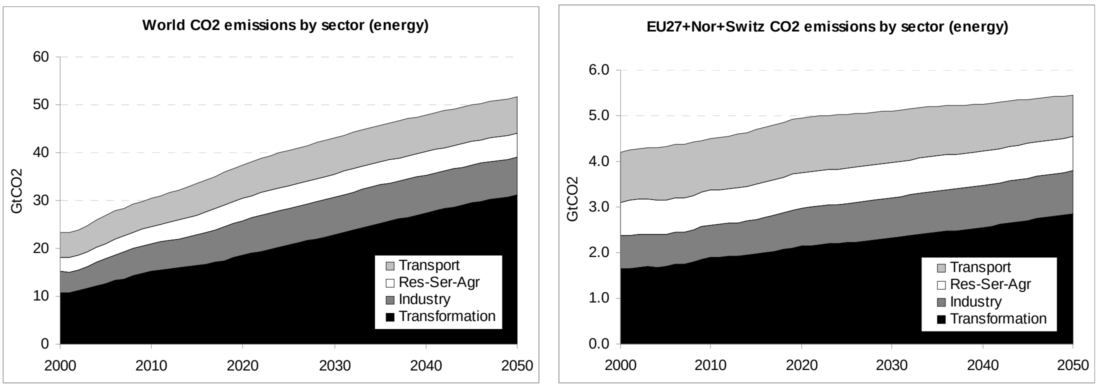
Source: POLES ADAM, Reference Sc.



Source: POLES ADAM, Reference Sc.

Figure 4-26: Participation of different groups in total European CO_2 emissions

The combination of the different trends results in significant structural changes in the energy system in Europe, even in the Reference case. These changes mostly result from the modest increase in total energy demand, while there is still a relatively high growth of electricity consumption, as described above. Associated with this penetration of electricity, the development of renewables and nuclear allows Europe's CO_2 emissions to stabilise by 2050 at 52 $GtCO_2$. This profile provides a consistent reference for emission trends, in this case without significant climate policies, which is of course not consistent with the type of international commitments that would adequately mitigate climate change. Stronger climate policies are needed and are examined in the next section.



Source: POLES ADAM, Reference Sc.

Figure 4-27: World and EU27+Nor+Switz CO_2 emissions by sector (energy)

4.3 Assumptions and results for the POLES model – the 2°C scenarios

4.3.1 Assumptions and methods for the 2°C scenarios

Most critical questions on how to attain the EU climate policy objectives still remain unanswered. The POLES model and scenarios developed in the ADAM project aim to introduce a more detailed treatment of new technology diffusion and thus to provide better insights into the role of these technologies in climate change mitigation policies: at what rate can clean technologies be deployed, how is it possible to accelerate their diffusion, what are the economic costs of the corresponding large-scale technological transitions?

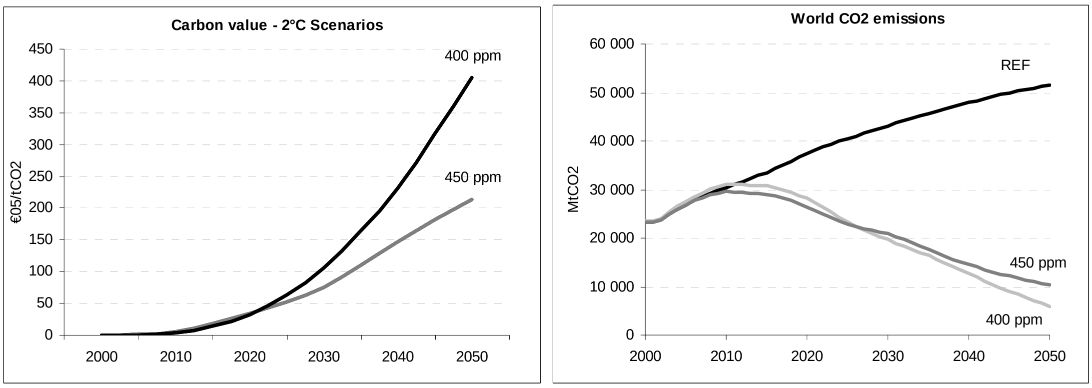
While some observers argue that radical technology breakthroughs will be required to solve the climate problem [Hoffert et al., 2003], others assert that existing technologies are sufficient to address the problem for the next half century [Pacala and Socolow 2004]. Most observers seem to agree, however, on the need for significantly increased investment in energy technology research and development [National Commission on Energy Policy 2003]. However, R&D activity is also an activity with strong uncertainties, and as such, any deterministic model is limited in its ability to characterise its potential benefits, particularly for disruptive technologies. Deterministic models do not take into account either uncertainty of future technology performances, and they do not endogenously simulate technological breakthroughs, which are by definition hard to forecast.

Given the capabilities of the POLES model in terms of energy technology description, the impacts of new and alternative technology pathways involving renewables, biomass, nuclear, hydrogen, carbon capture and sequestration and others have been examined in relation to their role in reaching the EU targets and in the dynamics of forming new technology paradigms.

The ADAM Reference scenario presented above provides a plausible projection of future energy use and carbon emissions until 2050, assuming that the current main trends continue and that these climate policies remain very modest. In the alternative scenario proposed below, a carbon value is introduced as representing a synthesis of the various taxes, emissions quotas, policies and other measures that may be combined to give a price to carbon and to achieve the desired emission reductions, in a "dose-response" type approach. This carbon value therefore is a good "proxy variable", reflecting the stringency of the policy measures to be implemented.

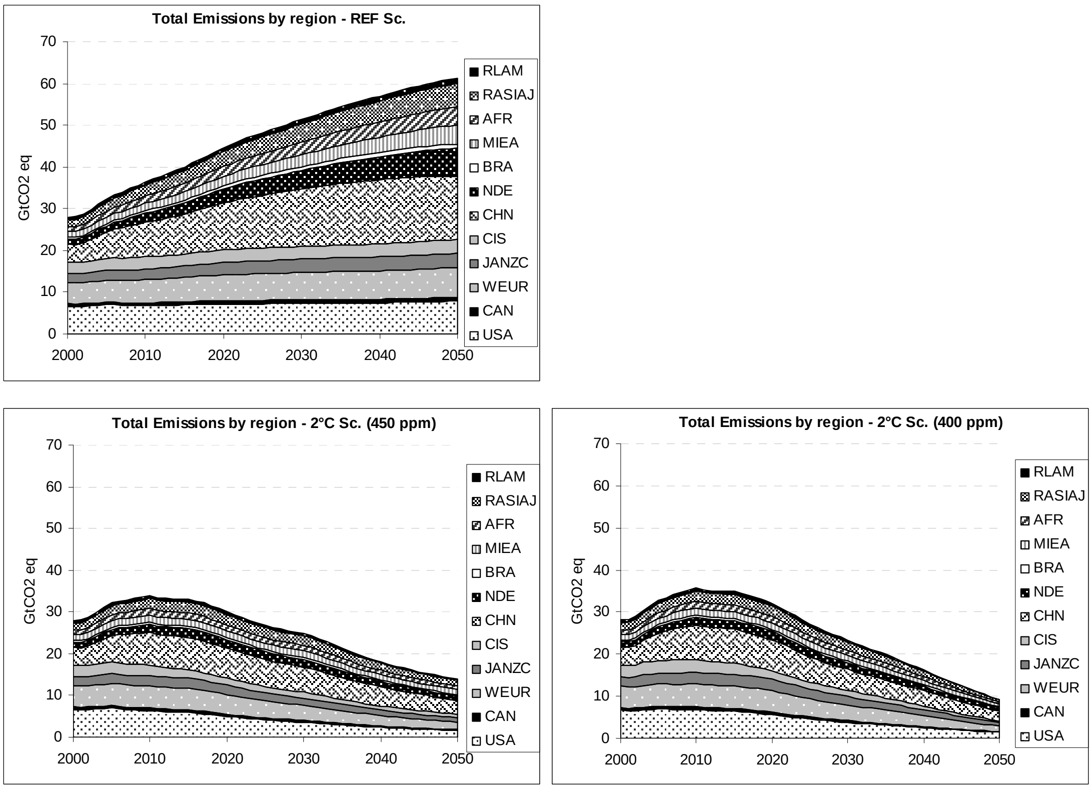
The 2°C scenario explores a severe GHG reduction profile, which implies a stabilisation of the concentration level at 450 ppmv CO_2e. This means that global emissions would peak before 2020, return to their current level before 2030 and then end up at one third of their current level by 2050. The results obtained for the carbon value provide two types of information that will be described below in the detailed analysis of the model’s results. First of all, it can be noted that in order to achieve the significant reductions in emissions after the peak is reached, the model's response functions require a sharp increase in the carbon value, since simulations with a moderate linear increase in the carbon value only induce a slowdown in emissions growth.

Secondly, this sharp increase illustrates the fact that in the energy system described in the model there is no "backstop technology" that would enable massive reductions when the carbon value reaches the threshold after which the backstop enters into the system. Although all low-carbon technologies are to some degree economically feasible at the carbon values considered, the full development of their potential implies a continuously improving economic environment. It is therefore necessary to promote high carbon values to reduce energy consumption and to accelerate the diffusion of very low-emission technologies. The high carbon value of 405 and 214 €05/tCO_2 in 2050 in the 400 and 450 ppm scenarios respectively achieves cuts in GHG emissions by 54 % and by 72 % in 2050 compared to 2005 respectively in the two 2°C scenarios.



Source: POLES ADAM, 2°C scenarios

Figure 4-28: Carbon value necessary to achieve objectives and the corresponding emission profile, 2°C scenario (400 and 450 ppm), 2000 to 2050



Source: POLES ADAM, 2°C scenarios

Figure 4-29: Total emissions by region, 2°C scenario (400 and 450 ppm), 2000 to 2050

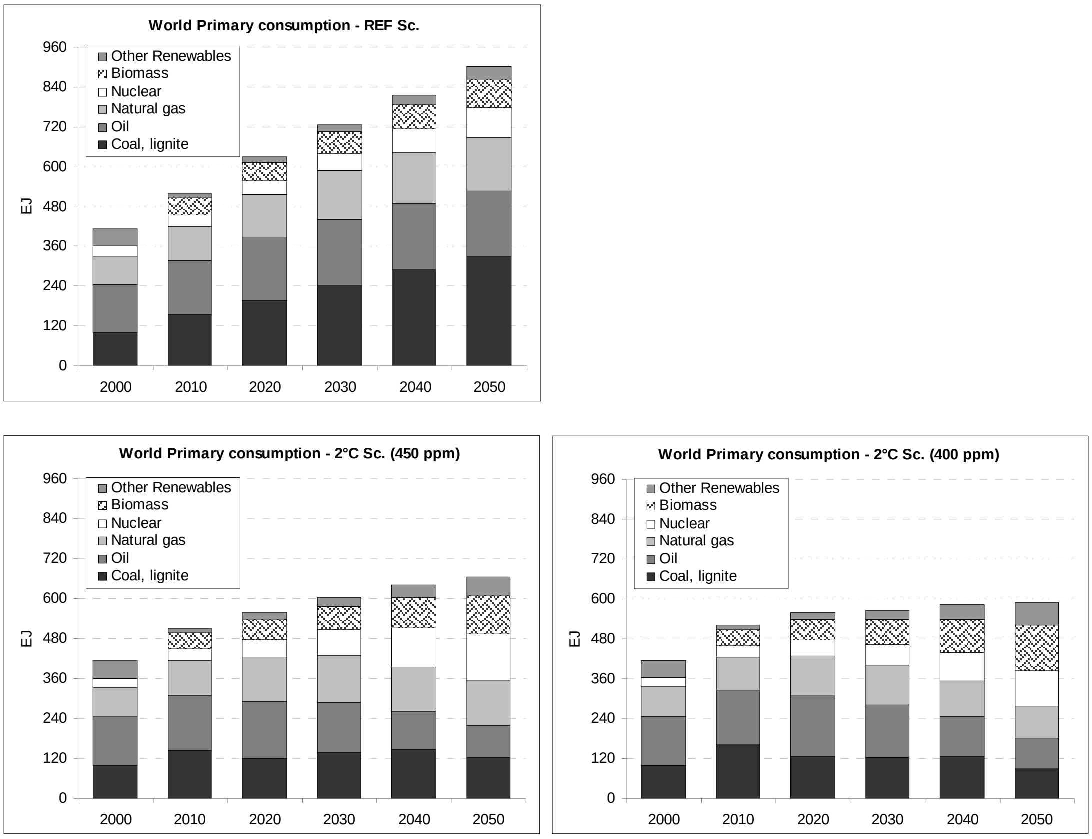
For companies in the power sector and energy-intensive industries, stricter greenhouse gas regulations designed to meet the Mitigation target will mean a shift in the global business environment, probably even greater than the one launched by the oil crisis in the 1970s. It may have a fundamental impact on key aspects of business strategy, such as production economics, cost competitiveness, investment decisions, and the value of different types of assets. Companies in these industries should therefore anticipate the effects of different types of greenhouse gas regulation, strive to adjust to it, and position themselves accordingly.

The first section below analyses the main consequences of this climate policy framework on energy supply and demand for Europe in a world context, while the second section deals with the resulting technological changes in the European power generation sector.

4.3.2 Results of the 2°C scenario to 2050

4.3.2.1 Impact on energy supply and demand

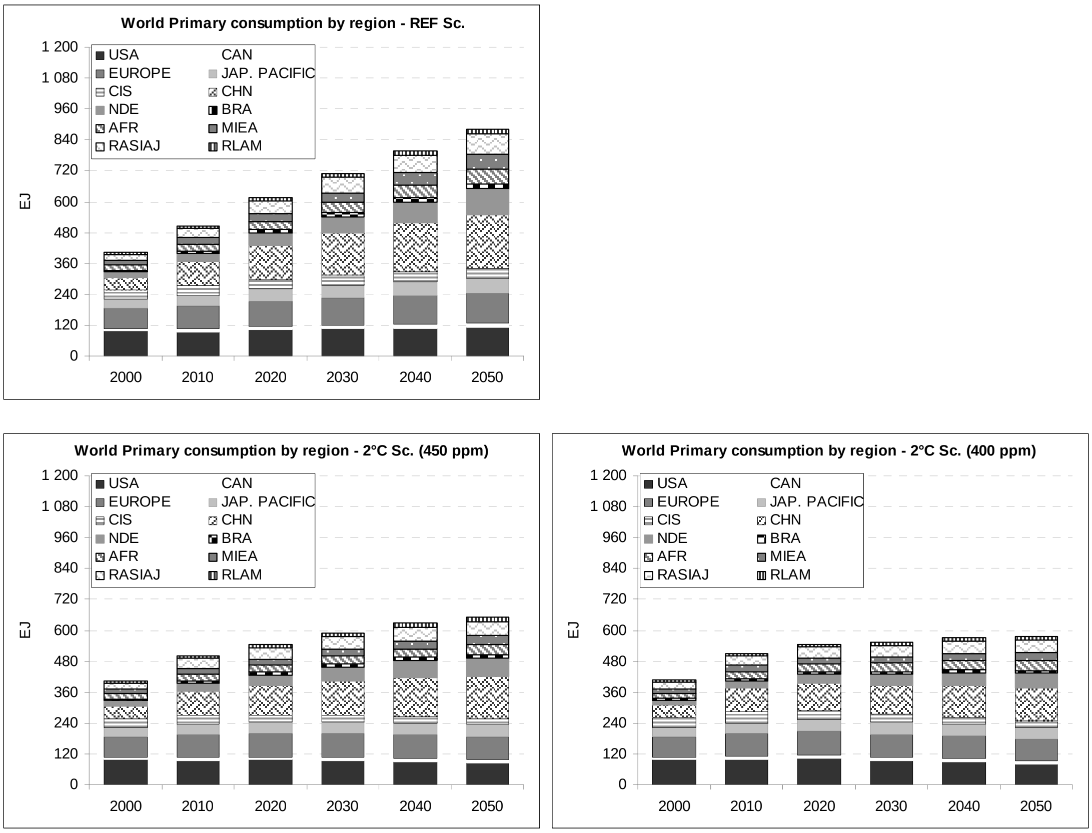
Unlike the Reference scenario, where world energy consumption more than doubled in 2050 in comparison to 2000, in the 2°C scenarios global energy consumption stabilises at a level of about 61 % and 42 % above that of 2000 respectively in 450 and 400 ppm. This shows that the answer to climate change is largely to be found on the demand side of the energy system. The introduction of a high carbon tax is particularly effective in reducing the demand for fossil fuels, which account for only half of the energy balance in 2050, as renewable and nuclear energy technologies which do not emit CO_2 become increasingly widespread.



Source: POLES-LEPII ADAM

Figure 4-30: World primary energy consumption by energy

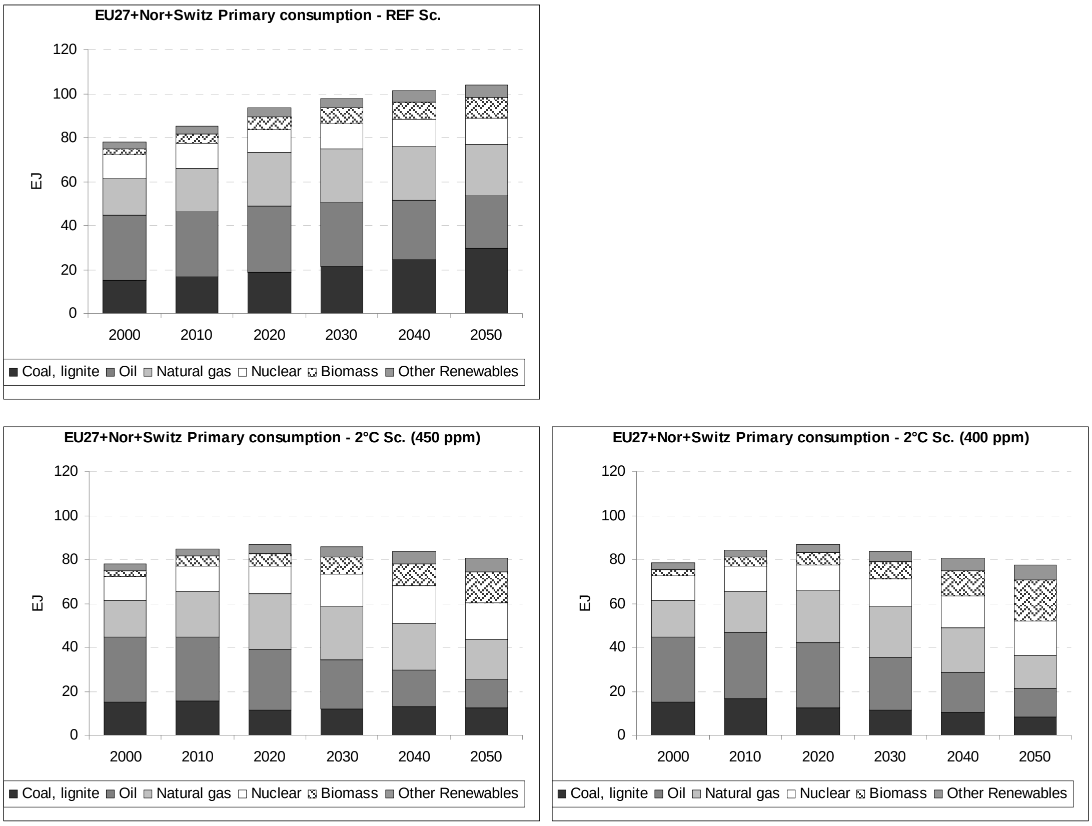
In terms of regional analysis, the energy consumption of the industrialised countries in the mitigations scenarios increases slightly until 2020 and then stabilises at the 2000 level. Although consumption in the developing countries continues to increase throughout the period, this growth is much slower than in the Reference scenario. Total consumption of the developing countries nearly triples, rising from 280 to 392 or 329 EJ in 2050. This increase reflects the fact that access to modern energy sources remains essential for poverty reduction and human development, even in a case of strong environmental constraint as examined here.



Source: POLES-LEPII ADAM

Figure 4-31: World primary energy consumption by region

The impact of the carbon tax is also significant for the level of energy consumption in Europe, as the 2050 level is nearly the same as in 2000.

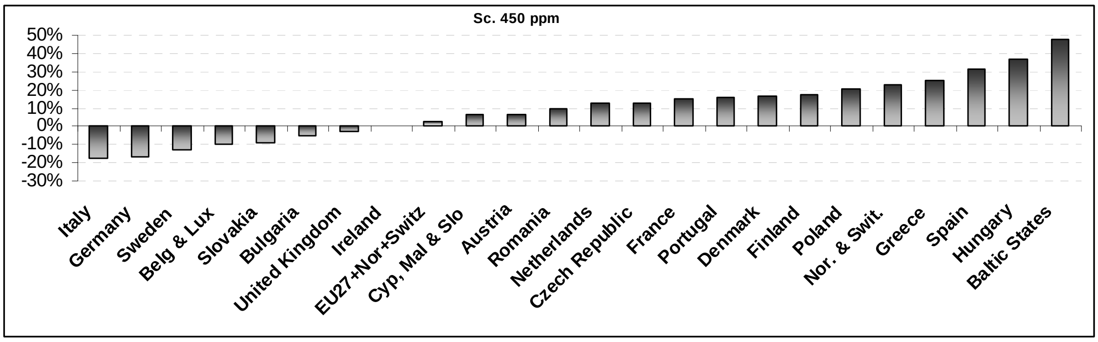


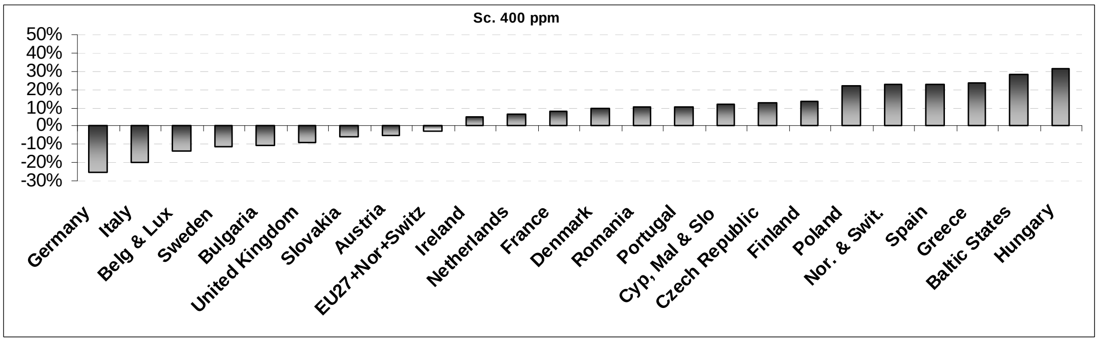
Source: POLES-LEPII ADAM

Figure 4-32: EU27+Nor+Switz primary energy consumption by energy

GHG emissions peak by 2020 and decrease considerably after that, representing only 49 % and 33 % of the current level by the end of the simulation in the 450 and 400 ppm scenarios respectively.

The impacts on energy consumption and emissions vary from country to country. At the end of the period, countries like Italy, Germany the Belgium & Luxembourg, Sweden, Slovakia seem to be much more strongly affected than the European average. Baltic Countries, Hungary, Spain and Greece increase their consumption in comparison with the current level (Figure 4-33).

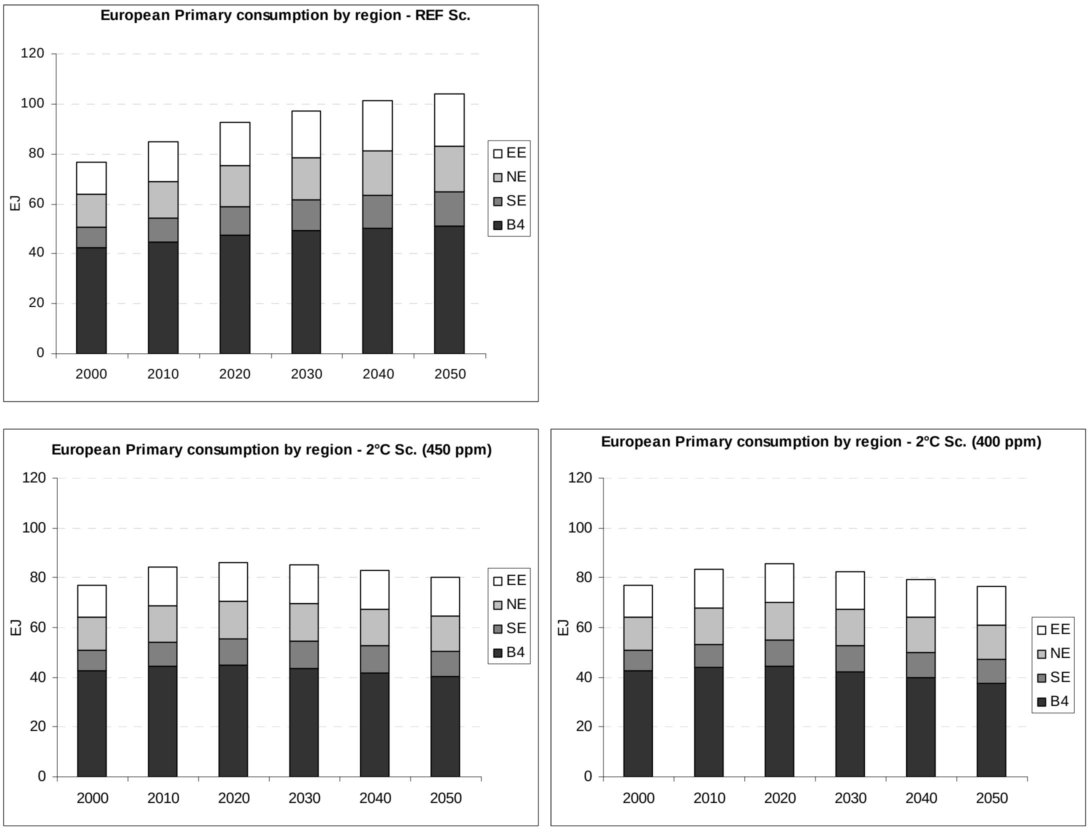




Source: POLES-LEPII ADAM

Figure 4-33: European primary consumption change in 2050 in comparison with 2000

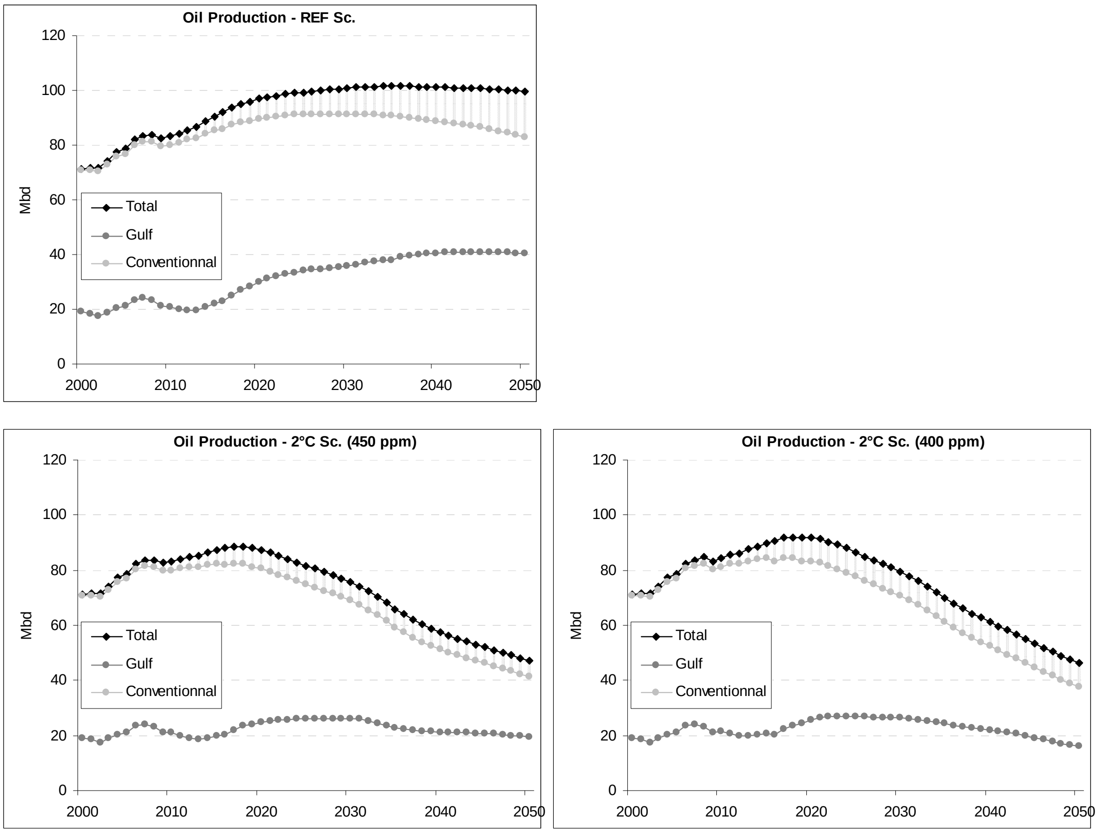
The Big Four and northern European countries (Figure 4-34) see their primary consumption increase until 2020, but this consumption decreases steadily thereafter, down to 43 % and 29 % respectively below the current level in 2050.



Source: POLES-LEPII ADAM

Figure 4-34: European primary consumption by region

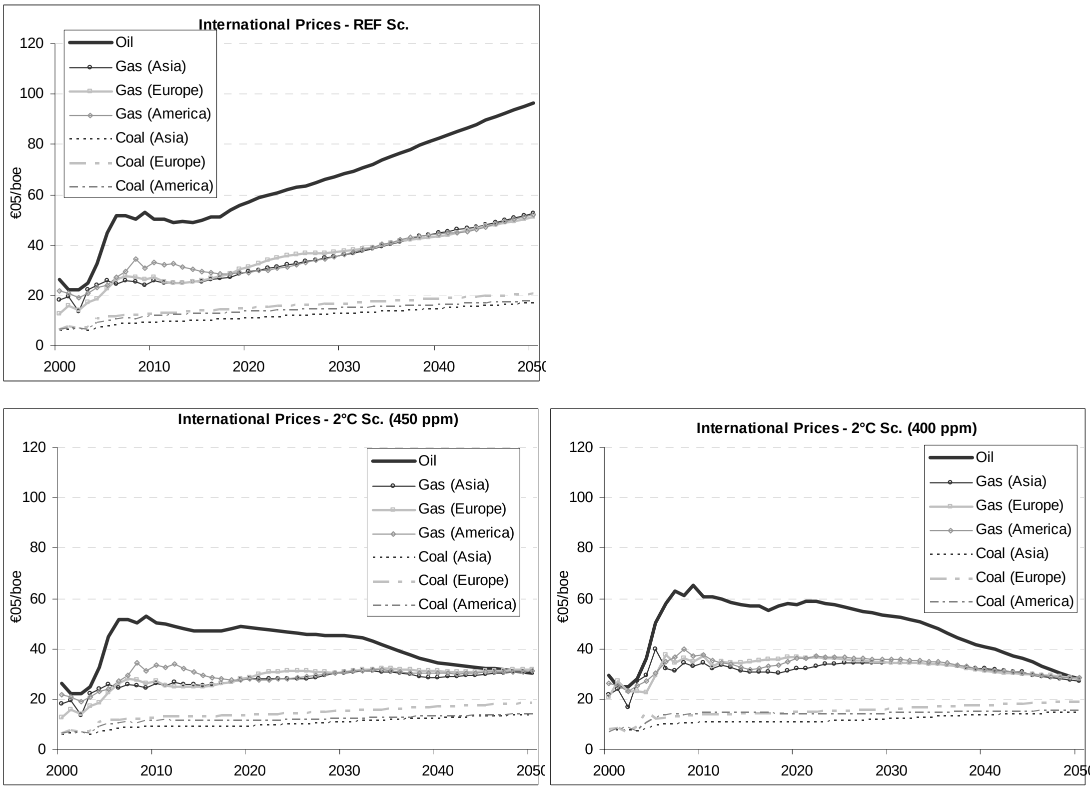
On the supply side, world crude oil production is similar to that of the 2°C scenario until 2015, since carbon taxes are roughly the same during this initial period. In the 2°C scenario production begins to decline in 2020, as the high and ever increasing carbon tax increasingly weighs on demand.



Source: POLES-LEPII ADAM

Figure 4-35: World oil production

After 2020, global crude oil and natural gas prices begin to be much lower in the 2°C scenario than in the Reference. However, it should be noted that these lower prices are only for oil and natural gas prices on the international markets or for imports. This lower level is of course not reflected in the prices charged to end-users and consumers, since the carbon tax component of the final price increases sharply.



Source: POLES-LEPII ADAM

Figure 4-36: Energy prices

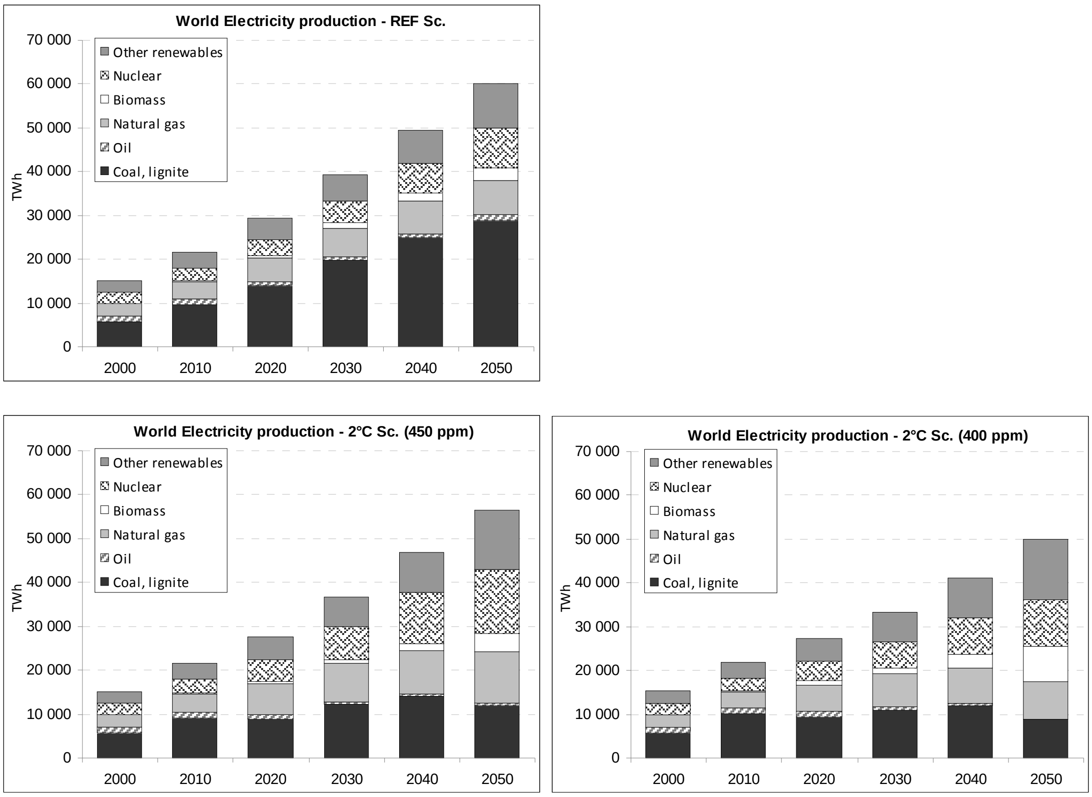
One of the most noteworthy differences between the Reference and the 2°C scenarios concerns the growth in total primary energy consumption and its structure. In the Reference scenario, because of the increasing scarcity of crude oil, there is a considerable increase in the use of coal, leading to dramatic developments for the global climate. On the contrary, in the 2°C scenario oil indeed becomes relatively more abundant and cheaper. This is probably the greatest "win-win" benefit for climate policies that has been identified so far.

4.3.2.2 Technological changes induced by the scenario

Drastic carbon emission reductions in the energy sector will be obtained both by reductions in the demand for energy and by modifying the corresponding supply-mix, in particular of electrical power. The first type of measures aiming at modifying the demand for energy includes the constant promotion of a high level of energy efficiency in all sectors and, in the longer term, the deployment of very low energy consumption technologies and equipment in the construction, transportation and manufacturing sectors.

The second category of measures includes four different options for "decarbonising" the energy sector, in particular power production. The first one is simply the substitution of natural gas for crude oil and coal, that takes advantage of the lower CO_2 content by unit of delivered energy of natural gas burning, while the three other options involve distinct families of technologies: renewable energies; nuclear power (using current technology reactors and new "fourth-generation" reactors); and finally, CO_2 capture and storage for large thermal power plants and other consumption units.

Although all of these actions are used to achieve the carbon emissions reduction target in the 2°C scenario, their respective contribution to emission reductions varies over the period. Initially, the bulk of reductions are obtained by substituting natural gas for coal and crude oil in those applications where these fossil fuels can easily be substituted, in particular in the generation of electrical power. Subsequently, cleaner power production technologies (renewable energy, nuclear power and carbon capture and storage) are sufficiently developed to achieve most of the reductions up to 2040. Towards the end of the period, the spread of "very low emissions" demand technologies in buildings where the long lifetime is a constraint to rapid deployment will once again make the greatest contribution to emission reductions.



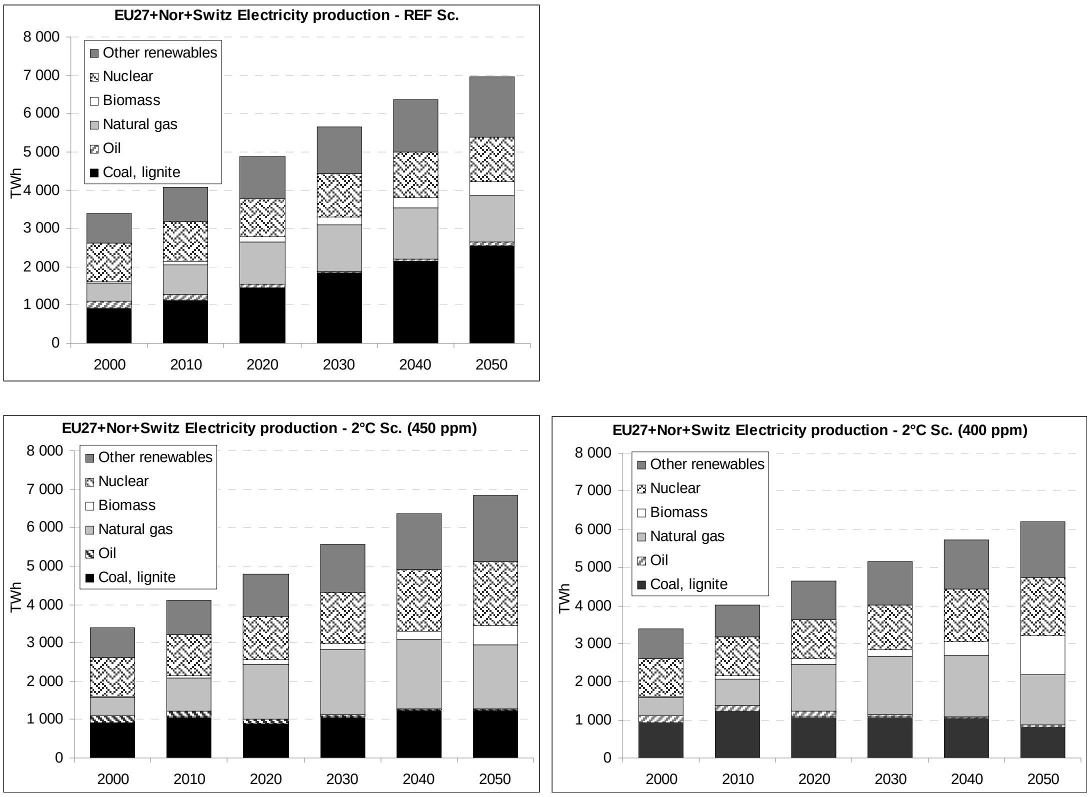
Source: POLES-LEPII ADAM

Figure 4-37: World electricity production

It should be noted here that renewable energies and nuclear power make an increasingly large contribution to the reduction effort, whereas the impact of carbon capture and sequestration technologies diminish at the end of the period, due to the increasing costs of storage sites and

CO_2 losses upon capture, which ultimately make these technology options quite sensitive to the high level of carbon tax.

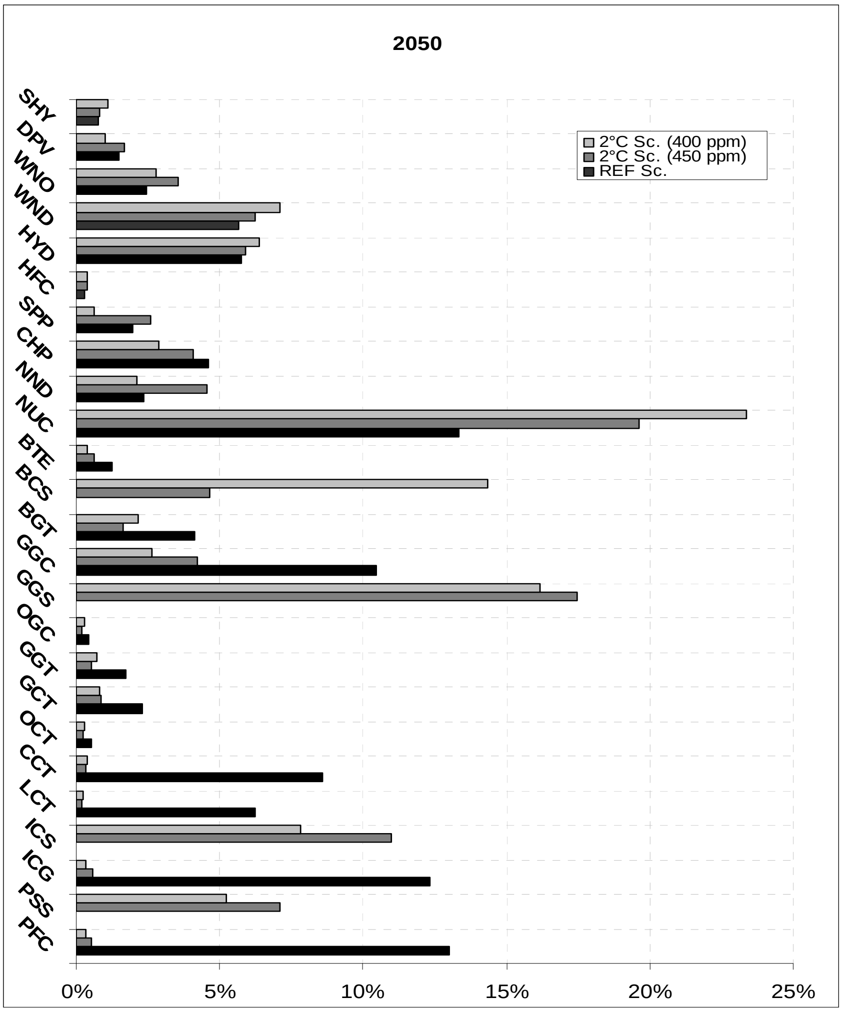
EU27+2 electricity production in the 2°C scenario (400 ppm), because of higher carbon value, is 9 % lower than in 450 ppm scenario, by 2050. Fossil fuels inputs for electricity generation shrink from 43 % in 450 ppm sc. to less than 36 % by the end of the period.



Source: POLES-LEPII ADAM

Figure 4-38: EU27+Nor+Switz electricity production

The impact of climate policy on the diffusion of different technologies is summarised in the following figure for the year 2050. In the 2°C scenarios, the technologies that show the greatest benefits are nuclear and CCS technologies, which represent respectively 64 % of the total EU27+2 electricity generation in 450 ppm and 69 % in the 450 ppm scenario compared to only 16 % of the electricity generation in the reference case.

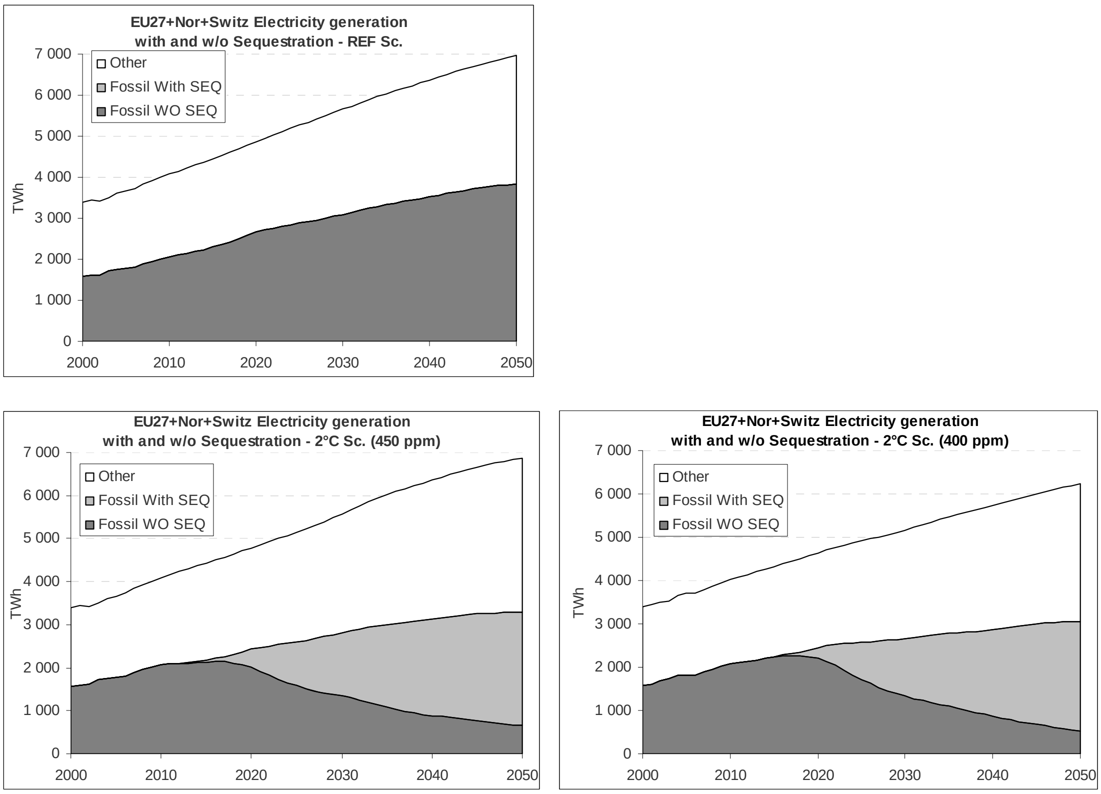


Source: POLES-LEPII ADAM[10]

Figure 4-39: EU27+NOR+SWITZ share of electricity production by technology in Reference (bottom bar), 2°C 450 ppm (middle bar) and 2°C 400 ppm (to bar) scenarios by 2050 in TWh

[10] SHY - Small Hydro Power plants (<10 MWe), DPV - Decentralised building integrated PV systems with network connection, WNO - Offshore Wind power plants, WND - Wind power plants for network electricity production, HYD - Conventional, large-size hydroelectricity, HFC - Stationary Fuel Cells with hydrogen, SPP - Solar Power Plants (thermal technologies for network electricity production), CHP - Combined Heat and Power (small to medium-size cogeneration in industry), NND - New Nuclear Design, NUC - Conventional Light-Water nuclear Reactor, BTE - biomass for thermal electricity, BCS - biomass for thermal electricity with sequestration, BGT - Biomass gasification for electricity production in GT, GGC - Gas-powered Gas Turbine in Combined Cycle, GGS - Gas-powered Gas Turbine in Combined Cycle with sequestration, OGC - Oil-powered Gas Turbine in Combined Cycle, GGT - Gas-powered turbine, GCT - Gas-powered Conventional Thermal, OCT - Oil-powered Conventional Thermal, CCT - Coal-powered Conventional Thermal, LCT - Lignite-powered Conventional Thermal, ICS - Integrated Coal Gasification with Combined Cycle with sequestration, ICG - Integrated Coal Gasification with Combined Cycle, PSS - Pressurised coal supercritical with sequestration, PFC - Pressurised coal supercritical.

While in the reference case, the technologies with sequestration do not appear at all, in the 2°C scenarios they represent 80 % and 83 % of the fossil based electricity generation respectively in the 450 and 400 ppm scenarios by 2050 (Figure 4-40).

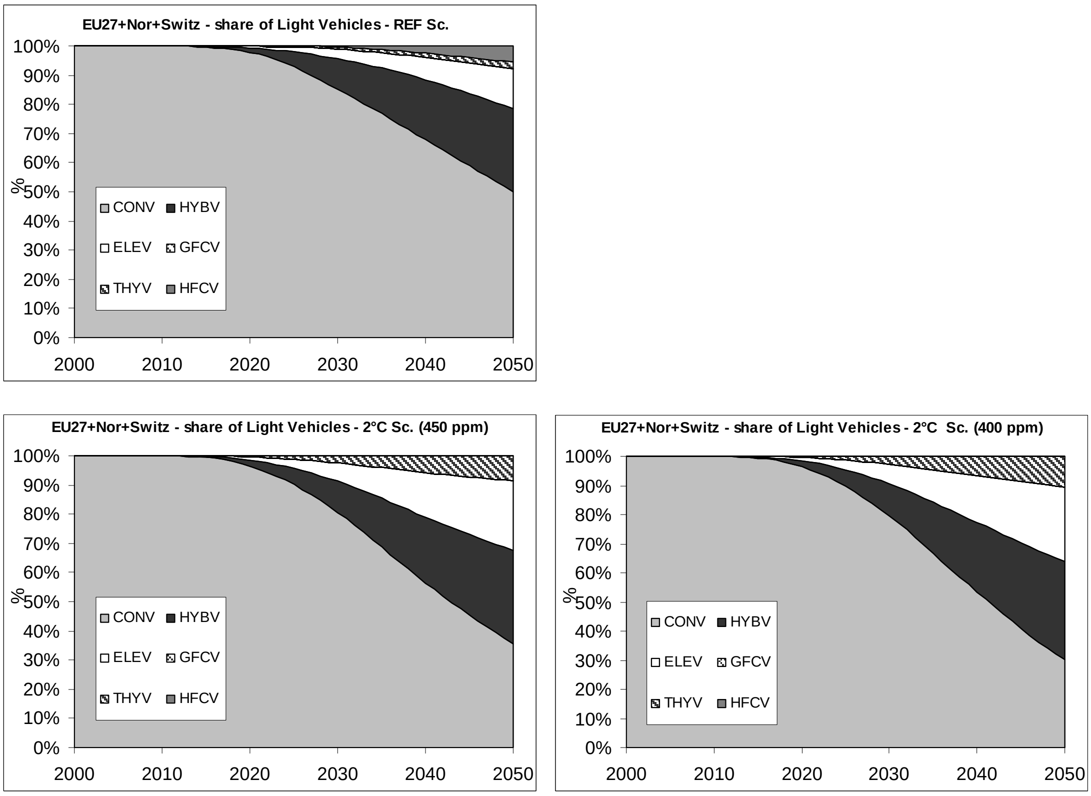


Source: POLES-LEPII ADAM

Figure 4-40: EU27 electricity production with and without sequestration

As indicated above, the 2°C scenarios have an impact not only on the diffusion of cleaner supply and conversion technologies, but they also accelerate the diffusion of new types of energy-consuming devices or infrastructures. Two key dimensions of this evolution are the development of very low energy (or positive) energy buildings, and the new low energy/emission vehicles.

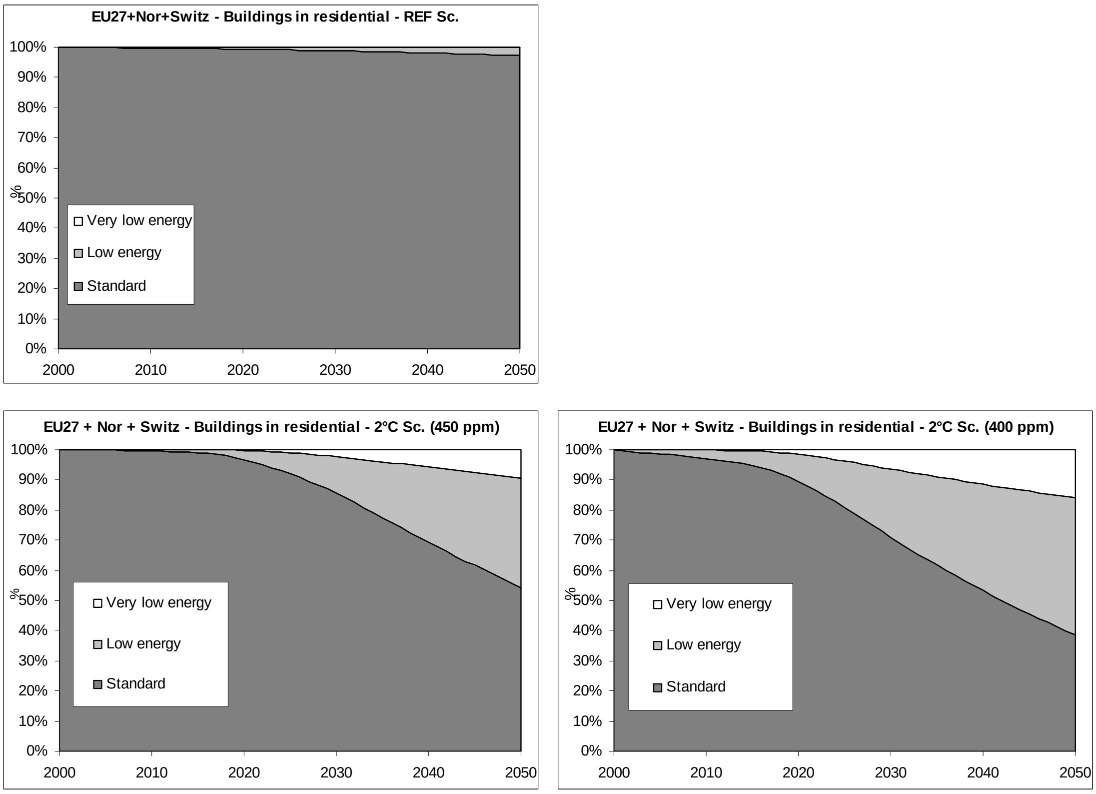
The shares of electric and hybrid vehicles rise by 2050 respectively from 14 and 27 % of the fleet in the Reference case, to 26 % and 34 % in the 2°C scenario 400 ppm.



Source: POLES-LEPII ADAM

Figure 4-41: EU27 diffusion of different types of vehicles in Mitigation and 2° C scenario

In the Reference scenario the share of low energy buildings in the residential sector is marginal, while in 2°C scenarios the share of low and very low energy buildings represents more than 40 % and 50 % of the building stock in Europe in 2050, in the 450 and 400 ppm scenarios respectively.



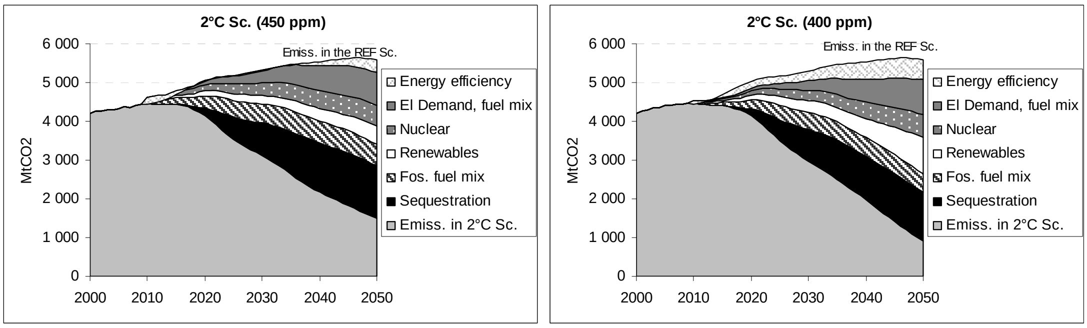
Source: POLES-LEPII ADAM

Figure 4-42: EU27 diffusion of different types of buildings in Reference and 2°C scenarios

In order to analyse the relative weight of the different options examined above, the contribution of six major options to emission reductions can be traced through the projection period:

1. Energy-efficiency and very low emission buildings and vehicles
2. Changes in fuel-mix at the demand level
3. Changes in fuel-mix in the electricity sector
4. Renewable energies
5. Nuclear energy
6. Carbon capture and sequestration

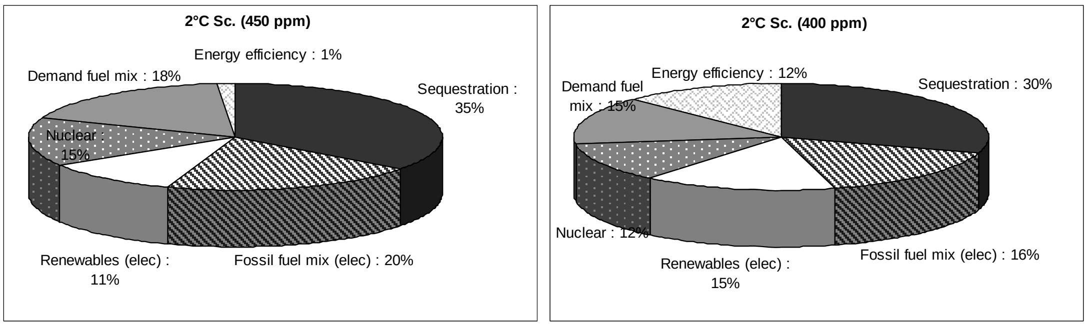
Although all of these actions are used to achieve the carbon emissions reduction target in the stabilisation 2°C scenarios (Figure 4-43), their respective contribution to emissions reduction varies over the period. Initially, the bulk of reductions is obtained by substituting natural gas for coal and crude oil in those applications where these fossil fuels may be easily substituted, for instance in the generation of electrical power. Thereafter, cleaner power production technologies (renewable energy, nuclear power and carbon capture and storage) make an increasingly large contribution to the reduction effort.



Source: POLES-LEPII ADAM

Figure 4-43: EU27+Nor+Switz annual contribution of various actions to reduce CO_2 emissions (Reference-2°C scenarios – 2000-2050)

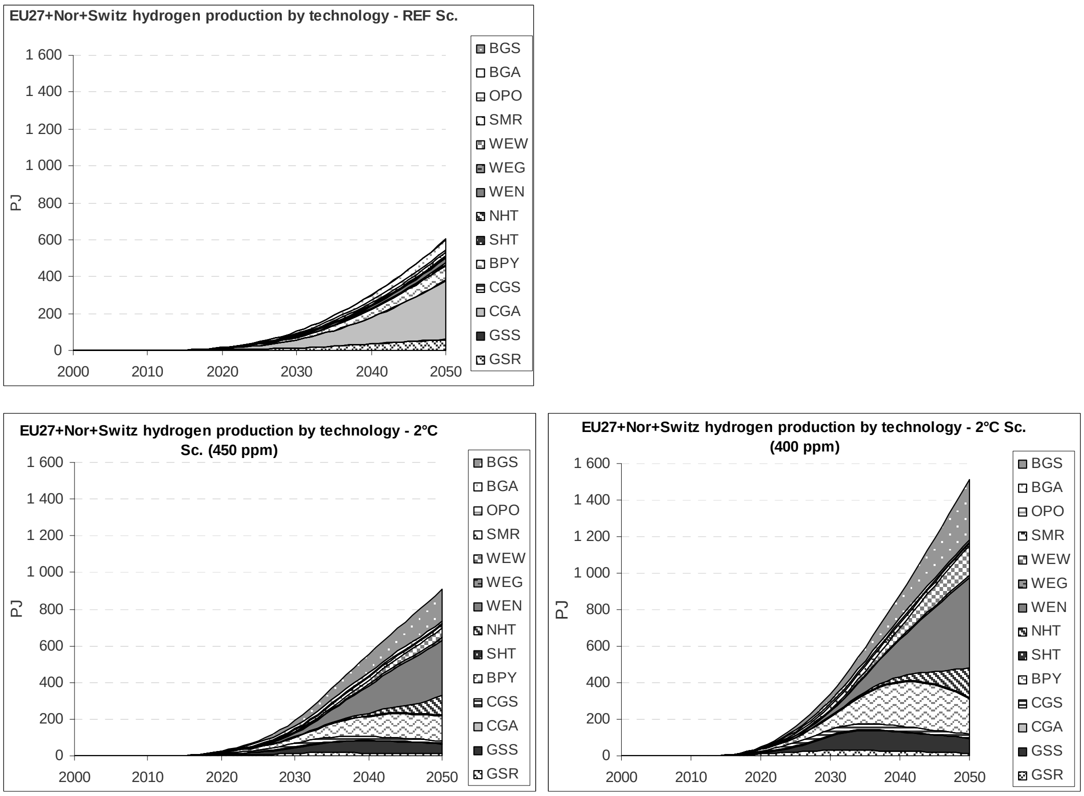
A look at the cumulative contributions of the various actions to reduce carbon emissions from 2010 to 2050 shows that carbon capture and storage play the biggest role in bothe scenarios, followed by demand-related actions (for 400 ppm sc.), developing renewable energies, and in equal proportions, increasing nuclear power production and fossil-fuel substitution (Figure 4-44). It should be noted that these contributions are measured with respect to the trend projection, which explains why the incremental contribution of capture and storage is relatively large (it is very low in the trend projection) and why the renewable energy contribution exceeds that of nuclear power, whereas the absolute contribution of nuclear power to the global energy balance slightly exceeds that of renewable energies in both cases.



Source: POLES-LEPII ADAM

Figure 4-44: EU27+Nor+Switz Cumulative contributions of CO_2 emission reduction measures (2°C scenarios – 2000-2050)

As far as hydrogen production is concerned, Figure 4-45 shows that the volume of the world hydrogen production does vary from 600 PJ in the Reference scenario to 900, 1500 PJ in the 2°C scenarios (450 and 400 ppm) respectively. The role of the different hydrogen production technologies is also significantly modified.

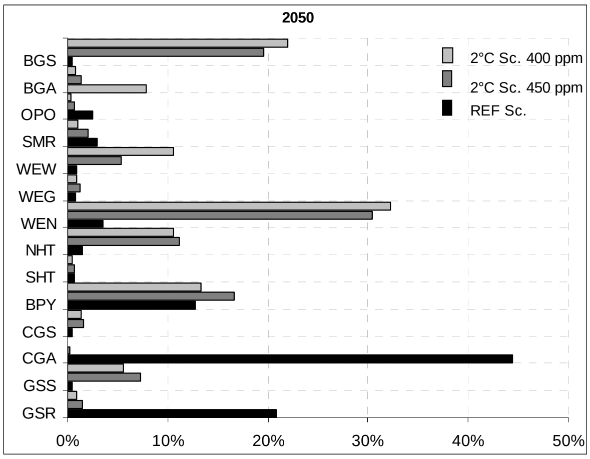


Source: POLES-LEPII ADAM[11]

Figure 4-45: Hydrogen production

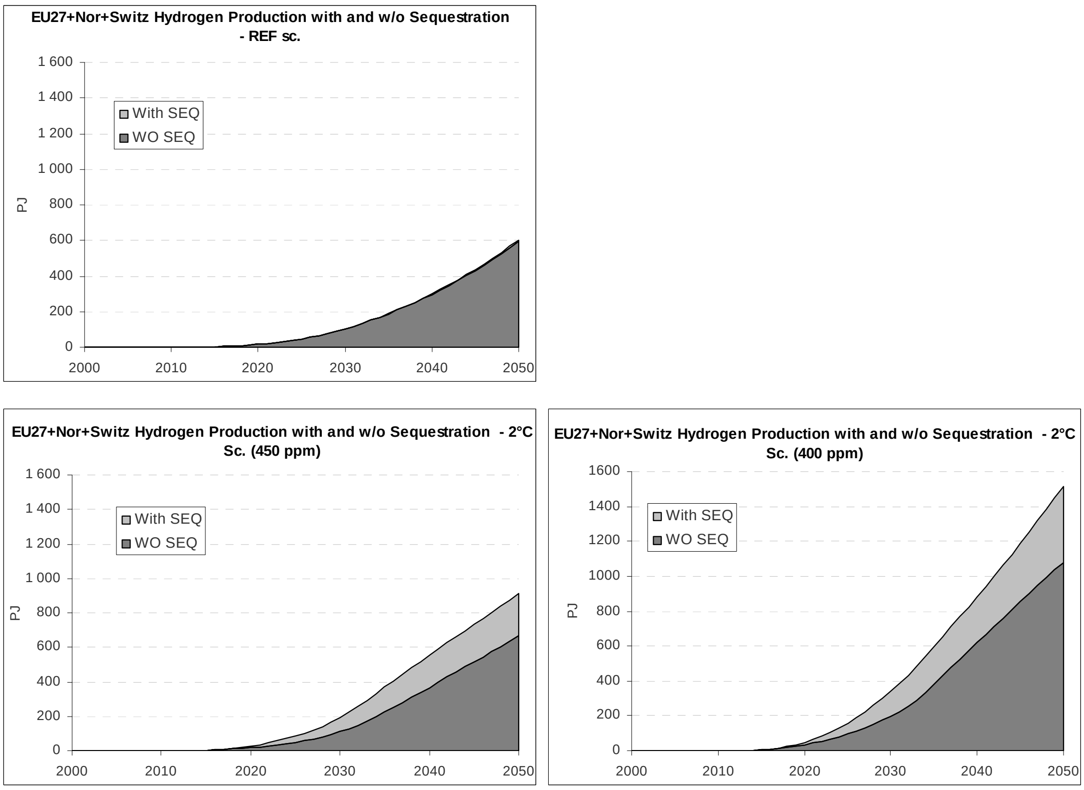
In the 2°C scenarios, the winning technologies are based on nuclear and biomass: hydrogen from water electrolysis nuclear dedicated (WEN), nuclear thermal high-temperature thermolysis (NHT), biomass gasification with sequestration (BGS) and biomass pyrolysis (BPY). Hydrogen production by these technologies represents around 79 % (400 ppm sc.) by 2050. 29 % of hydrogen production is provided by technologies with sequestration (see Figure 4-47).

[11] Where: BGS- Hydrogen from biomass gasification with sequestration, BGA- Hydrogen from biomass gasification, OPO - Hydrogen from Heavy Fuel Oil Partial Oxidation , SMR - Hydrogen from Solar Methane Reforming, WEW - Hydrogen from Water Electrolysis dedicated Wind power plant, WEG - Hydrogen from Water Electrolysis baseload electricity from Grid, WEN- Hydrogen from water electrolysis nuclear dedicated, NHT - Hydrogen from nuclear thermal high-temperature thermolysis, SHT - Hydrogen from solar thermal high-temperature thermolysis, BPY - Hydrogen from biomass pyrolysis, CGS - Hydrogen from Coal Gasification with sequestration, CGA - Hydrogen from Coal GAsification, GSS - Hydrogen from Gas Steam Reforming with sequestration, GSR - Hydrogen from Gas Steam Reforming.



Source: POLES ADAM, 2°C scenarios

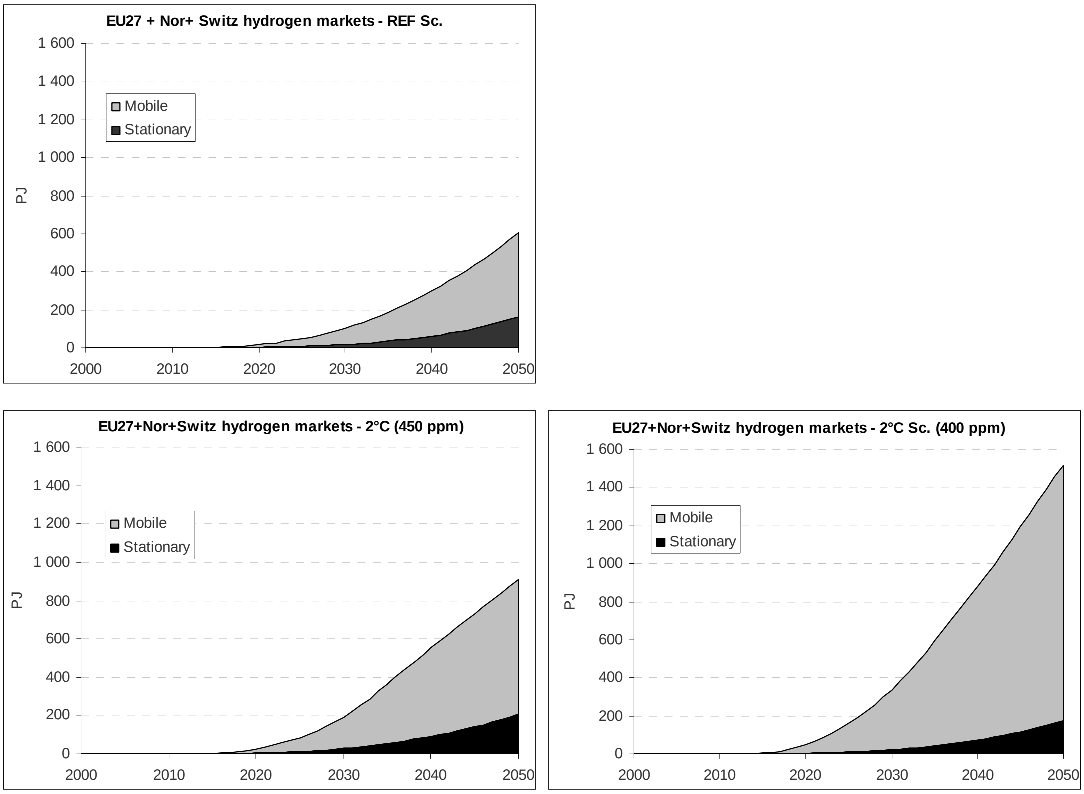
Figure 4-46: Share of EU27 hydrogen production by technology in Mitigation (top bar), MITIGATION (low bar) scenarios in 2050 and 2050a in the world level



Source: POLES-LEPII ADAM

Figure 4-47: EU27+Nor+Switz Hydrogen production with and without sequestration

Mobile uses of hydrogen are more important in the three scenarios compared to stationary uses. However, the share of the mobile markets is much more important in the 2°C scenarios than in the reference case (Figure 4-48).



Source: POLES-LEPII ADAM

Figure 4-48: EU27 hydrogen markets, in Reference and 2°C scenarios

4.4 Conclusions on policies and reduction strategies by POLES

The key insights of POLES in the ADAM project for the European energy technology policies can be summarized as follows:

- As already known, there is no silver bullet in climate policies, all the wedges of emission reductions have to be activated through time.
- Energy efficiency can be triggered in the short term through carbon pricing, while the diffusion of Very Low Energy Buildings and Very Low Emission Vehicles are important to emission reductions in the long term.
- Carbon Capture and Storage is an important option in the medium term, since from 2020 to 2050 it plays a major role in the decarbonization of the electricity sector.

- Renewables and nuclear energy seem to play a somewhat minor role in the transition from Reference to 2°C; but this is largely an error of perspective as their development presupposes a major research and investment effort which is already in the Reference case.

In order to foster the decarbonization of the European energy system comprehensive policies should certainly:

- Give a price to carbon; this will provide the pervasive signal that is necessary for the taking into account of the carbon constraint by all economic agents … as for the triggering of private R&D in low carbon technologies.
- Develop massive public R&D policies in the four main areas of emission reduction and low-carbon supply: end-use technologies, renewables, nuclear and carbon capture and storage.
- Accelerate the dissemination of the low carbon technologies through norms and standards wherever it is appropriate: buildings, vehicles power plants etc.
- Create the urban and transport infrastructures that will allow reducing the energy needs and accelerating the diffusion of low carbon technologies.

5 Forest and basic materials sector

Authors: Mart-Jan Schelhaas, Laura Quandt

5.1 Forest sector

5.1.1 Target of analysis

Forests of the EU 27+2 countries comprise some 156 million ha, or 34 % of the land surface. Since most of these forests are harvested for only about 60% of their increment, a vast resource of stemwood standing stock has developed over the last decades. This and the generally good accessibility of the forests, makes that biomass from these existing forests is seen as potentially a significant source of raw material for bio energy purposes. In earlier analyses, the technical potential for delivery of biomass from forests has been quantified until 2050 (Jochem et al., 2007; Jochem and Schade, 2008), assuming an unchanged demand for other wood products. This technical potential has been used in the model system (mainly PowerAce) of M1 to ensure that the use of forest biomass in the energy system was within sustainable limits. Apart from the use of biomass for bioenergy, forests deliver the material for many products like paper and construction timber. Within M1, this type of demand is quantified by the MATEFF model. In this chapter, we describe how the combined demand for conventional wood products and biomass for bioenergy as defined by the M1 model system affects the carbon sink in the forest, using the EFISCEN model as before.

5.1.2 Assumptions and model rationale

EFISCEN is an area-based matrix model that simulates the dynamics of the stemwood volume in a forest (Schelhaas et al. 2007), given a certain harvest level and basic management regime. For other tree organs as leaves, branches and roots, a detailed biomass expansion database is incorporated. The soil model YASSO (Liski et al., 2005) is incorporated to project development of soil carbon stocks, given inputs from litter turnover and harvest residues. Basic outputs of EFISCEN are developments of area, standing stock, increment, standing dead wood, harvest level, extracted residues, age class distribution, and carbon stock in soil and biomass over time. EFISCEN can be used to give projections of wood production and carbon stock changes in tree biomass and soils in European forests up to many decades (Nabuurs et al. 2007, Schelhaas et al. 2007).

Projections made with EFISCEN are initialised making use of detailed national forest inventories that were specifically gathered for this purpose from National forest inventory institutes. The standard EFISCEN management regimes were used in this study (Nabuurs et al., 2007); nature oriented management in forestry or adaptation of forest management to climatic change was not taken into consideration. Climate change effects on forest growth were incorporated, based on the process-based model chain SMART-SUMO-WATBAL (Wamelink et al., 2009), which was applied to Intensive Forest Monitoring level plots in mid and high latitudinal Europe (Pussinen et al., 2009). For Southern Europe, expected impacts were based on a literature survey. Effects of climate change on extreme events (fires, storms) were not taken into account.

For the period 2010-2050, total demand for conventional products and biomass for energy was delivered by the other models within ADAM, given in m^3 wood underbark. This was multiplied with 1.12 for conversion to overbark, as needed by EFISCEN. From the results of the Reference scenario we calculated for each country which fraction of the total removed biomass was covered by extraction of forest residues. This fraction was used to calculate total stemwood demand from the total demand. The fraction of residues from thinnings and fellings (branches, tops and roots) that is extracted from the forest was assumed to be unchanged as compared to the Reference Scenario. Before 2010, harvest was derived from FAOSTAT data (FAOSTAT 2008). Results are presented for four country groups (see Table 5-1).

Table 5-1: Division of European countries into four regions

Central\western Europe	Austria
	Belgium/Luxembourg
	France
	Germany
	Ireland
	the Netherlands
	Switzerland
	United Kingdom
Mediteranean	Italy
	Portugal
	Spain
Scandinavia	Denmark
	Finland
	Norway
	Sweden
Eastern Europe	Bulgaria
	Czech Republic
	Baltic states
	Hungary
	Poland
	Romania
	Slovakia
	Slovenia

5.1.3 Results

The total demand for wood from the forest is projected to increase from slightly under 600 million m^3 underbark in 2010 to over 900 million m^3 by 2050 (Figure 5-2). Most of this increase is caused by increased demand for biomass for heat and especially electricity. In 2010, the majority of the demand is still for conventional products (62%). By 2050, equal shares of the demand are for products and biomass for heat or electricity.

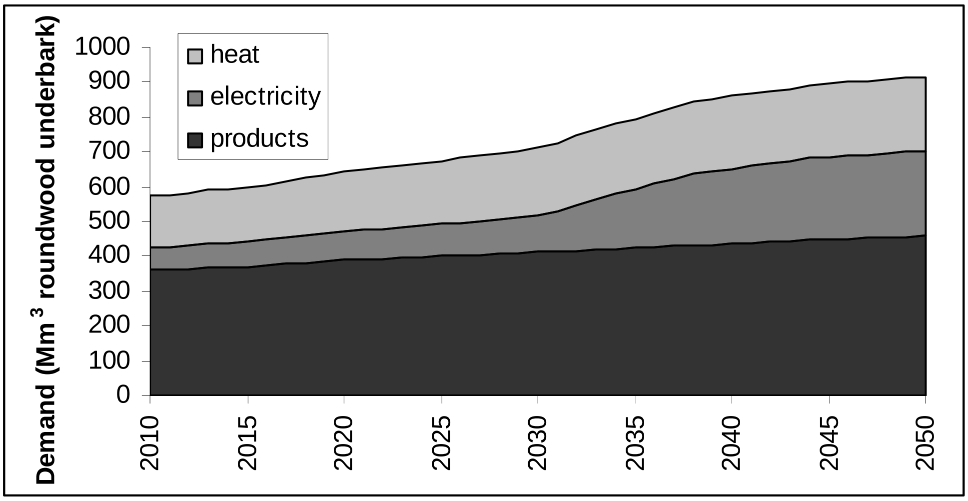


Figure 5-1: Demand for domestically produced wood as given by the M1 modelling system, expressed in roundwood volume equivalents, 2010 to 2050.

The gradual increase in harvest level slows the build-up of stemwood standing stock (Figure 5-2B). Eventually the stemwood standing stock stabilizes in most regions. As a consequence, the total carbon sink in the forest is decreasing over time, from 128 Tg C/yr in 2005 to 85 Tg C/yr in 2050 (Table 5-2). The soil sink is rather stable, amounting to 30-40 Tg C/yr for total Europe. Only in the Mediterranean region it is a small source around 2015. The biomass sink for total Europe displays more volatility, starting at 100 Tg C/yr, decreasing to 36 Tg C/yr by 2040, and increasing again afterwards. This volatility is caused by opposing patterns in the different regions. In Central/Western Europe and Eastern Europe the biomass sink is currently rather high, but declines to virtually zero in 2050. In Scandinavia, the biomass sink is increasing after 2040, due to increased increment in this region due to higher temperatures. In the Mediterranean region, the biomass sink gradually increases towards 2030 and decreases afterwards, due decreased increment caused by climate change.

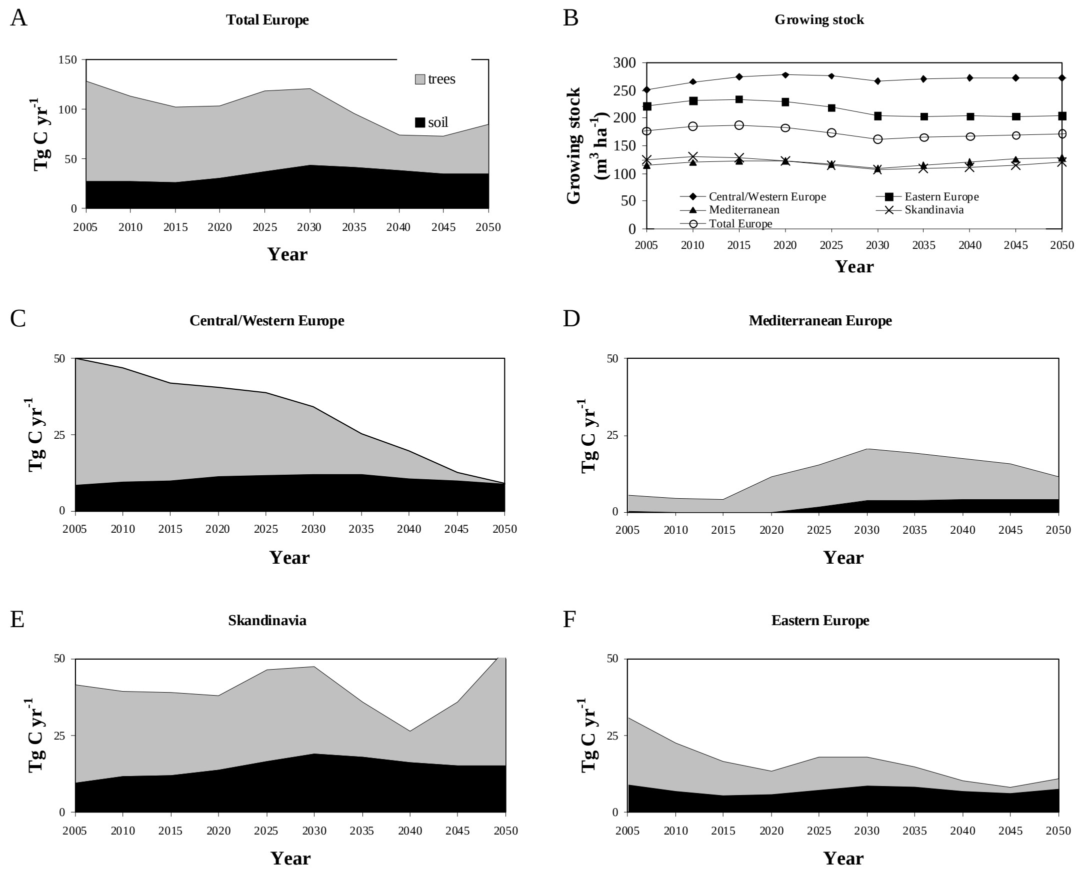


Figure 5-2: Carbon sink in the soil and biomass compartments (Tg C/yr) for Europe (A) and the four regions (C-F), and development of average timber stock (B, m^3/ha).

Table 5-2: Total carbon sink in the forest (biomass plus soil, Tg C/yr) per region and for total Europe, 2010 to 2050

Country group	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Scandinavia	42	39	39	38	46	48	36	26	36	53
Central/Western Europe	50	47	42	40	39	34	25	20	13	9
Eastern Europe	31	22	17	13	18	18	15	10	8	11
Mediterranean	6	5	4	12	15	21	19	18	16	12
Europe	128	113	102	103	119	121	95	74	73	85

The total demand for wood and biomass is very close to the maximum the forest can deliver, as was specified by EFISCEN under climate change conditions (Jochem and Schade, 2009). As a consequence, the mitigation function of the forest is shifting from physical carbon storage in the biomass and soil towards avoiding greenhouse gas emissions from fossil fuels by delivering biomass for bioenergy. The carbon that is released by burning of the biomass will be taken up by the vegetation again, and thus this process is seen as carbon neutral (apart from emissions in harvesting, processing and transport). This cycle can be repeated endlessly, without risk of loosing previously gained carbon. The opposite is true for carbon storage in biomass and, to a lesser extent, soil. Storage of carbon in the forest biomass will reach a limit sometime, and there is always a risk that part of the carbon stored will be released again, for example due to disturbance events. Kundzewicz et al. (2009) studied the future risk for disturbances (fires and storms) in the forest and possible adaptation measures in the A2 workpackage within the ADAM project. Under climate change, forest fires are expected to become more common, and storm activity might increase as well. An increase in harvest level will contribute to limit the risk of wind damage in forest, by limiting the numer of old stands and the amount of timber (and thus carbon) present in the forest (Kundzewicz et al., 2009). However, at the same time it increases the risk of forest fires, since more stands will be in the vulnerable young stage (Kundzewicz et al., 2009). However, the removal of harvest residues from the forest decreases the fuel load for fires and might contribute to lower the risk. This factor was not taken into account by Kundzewicz et al.

A very uncertain factor is how much climate change will influence the growth of the forest. The potential for delivering biomass from the forest increased by 20% in 2050 when the effects of climate change where taken into account. If climate change will have less effect on the increment, the harvest level cannot increase as far as suggested in this scenario. Therefore, it will be very important to monitor the forest growth in future and adjust harvest levels and industry expectations based on this.

Although an increase in harvest level and removal of harvest residues is needed and even preferable in some cases, it is the question if it can be realised to this extent. Increased harvest and residue removal might conflict with other functions of the forest, like nature conservation, soil and water protection and recreation. Furthermore, many forest owners seem to be not sensitive to financial stimuli in their forest management. Subsidies and increased prices might therefore not be enough to increase the harvest level to the extent needed as sketched by the M1 modelling system. Currently, several studies are looking into alternative ways to stimulate owners to mobilise their wood resources.

5.1.4 Conclusions

In order to reach the target for the 400 ppm scenario, the harvest of wood and extraction of residues need to be increased close to the maximum the forests can sustain. As a consequence, the carbon sink in biomass and soil will decrease, which will be (partly) compensated for by avoided emissions from fossil fuels. An increased harvest level will contribute to limit the wind risk in forests. The effect on fire risk is not clear, with increased risk due to an increasing number of young stands and decreased risk due to lower fuel load when harvest residues are removed. Part of the increase in harvest level can be obtained due to expected positive effects of climate change on the growth of the forest. However, the exact magnitude of the effect is still unsure, and close monitoring of the balance between growth and harvest is needed. In order to reach the required harvest level, much effort will be needed in the policy domain to convince forest owners to harvest more. Such efforts could include for example full-service contracts to small private owners, support to ownership co-operations, support in making management plans, awareness campaigns about the environmental benefits of biomass harvest, and stimulation of integration of different types of measures with biomass removal (nature conservation measures, fuel reduction against forest fires).

5.2 Assumptions and results of the MATEFF model – Reference and 2°C Scenario - 2000 to 2050

The model used for simulating the development of energy-intensive materials and products is called MATEFF (derived from material efficiency). The production of such energy-intensive products and materials is an important driver of industrial energy demand. However, the results of the projections of the macroeconomic models given as value added or net production of these basic materials do not reflect the development of the physical production of these materials, because quality improvements increase the value added, increasing rates of recycling or additional services of the related industrial sectors (e.g. consulting, product development for customers) add to intra-industrial structural change. It is important, therefore, to consider these aspects in the Reference Scenario as normal intra-industrial structural change and as a policy option of climate change in the 2°C Scenario. If these aspects and policy options of material efficiency – in form of less use of material for the same product function (e.g. lighter cars by using thinner steel sheets), material recycling (e.g. paper, aluminium, glass, copper) and product re-use (e.g. truck tires) - are not taken into consideration, the energy demand projections and related CO_2 emissions of energy-intensive bulk product will be overestimated when they take the value added data of the macroeconomic models as the driver for energy demand.

MATEFF, therefore, is an important part of the TRANSFORM module of the hybrid model system (HMS) to transform the value added or net production figures of the macroeconomic models into physical production figures that can be directly related to energy demand by technical data of specific energy demand of the related products in industry (see Chapter 8). The MATEFF model is shortly described in Chapter 3 and was specifically developed ion the ADAM project. in order to demonstrate the important role of material efficiency policies as a part of an ambitious climate change policy reflected in the 2°C Scenario.

5.2.1 Assumptions about the demand of energy-intensive products

The assumptions for the development of the physical production of energy-intensive materials were based on two alternative methods:

- Trend estimates of per capita production of the energy-intensive basic products is one option, particularly if saturation effects were able to be observed in the past, or are anticipated in the future, or
- the use of a statistically estimated relation between the economic production figures of the basic material industries projected by the macroeconomic models and the physical production of the basic products which often reflects the trends to higher value added, higher material quality and improved properties.

The following sections briefly describe the assumptions and method used for the main basic materials such as steel, aluminium, glass, paper, cement, and plastics. The assumptions and results concerning the different industrial sectors are identical in the Base Case Scenario (see Deliverable M1.1: Report of the Base Case Scenario for Europe) and the Reference Scenario (see Chapter 5.2.1.1). In contrast, the assumptions of the 2°C Scenario are quite different and assume rapid progress in material efficiency in order to reduce industrial energy demand in the basic product industries (see Chapter 5.2.1.2).

A few of the projections for energy-intensive products presented in Deliverable M1.1 have been revised due to new data. The assumptions and results of the Reference and the 2°C Scenario are described in the following sections or in the ANNEX , Chapter 16.2).

5.2.1.1 *Reference Scenario – 2000 to 2050*

The results of this scenario reflect the trend to material efficiency and intra-industrial structural change without any additional attempt to reduce the demand of energy-intensive materials.

Assumptions about the drivers of steel production in Europe

Steel is a much valued basic material with numerous uses as a raw material, half-finished product, finished product, transformed product or processed product. An enormous increase in competitiveness (improvement of energy and resource efficiency, minimisation of CO_2 emissions, new steel grades, innovative and efficient steel production technologies) is apparent in every field of steel production.

World steel production has been increasing continuously at high rates since 1970. In 1970, world crude steel production equalled 595 million tonnes. In 2006, 1,240 million tonnes of crude steel were produced globally, worth around 670 billion €. There has been particularly rapid growth in steel production in China and India, demonstrated by the fact that 422.7

million tonnes of crude steel were produced in China in 2006, which translates to about 324 kg/capita and year.

In comparison, the EU27 produced 206.8 million tonnes of steel in 2006 even though the European Union (485 million inhabitants) is a leading steel market (426 kg/cap. per year). In 2006, in the EU27, the share of oxygen steel was 59.6 % and the share of electrical steel 40.1 %. Electrical steel is made out of steel scrap, whereas oxygen steel is mainly produced as a primary material from iron ore in blast furnaces. There is a large share of electrical steel in the highly industrialised countries of Europe with large capital stocks, which will continue to increase in the future.

Based on the production of oxygen steel and electrical steel in the year 2005, the development of steel production was estimated for EU27 (+ Norway, Switzerland, Turkey) by projecting the steel production per capita of the European countries in the years 2020, 2030, 2040 and 2050 (see table 16-4 and Table 16-5). The data between these reference points were calculated as a linear increase or decrease. When estimating per capita steel production, two different trends have to be considered for the next decades:

- The older the capital stock of an industrialised country, the more steel scrap becomes available. This increases the potential for electrical steel production in the country considered.
- The more industrial goods with steel parts are imported into a country, the more likely it is for domestic steel production to be reduced, particularly oxygen steel.

As a result of these basic trends, increasing shares of electrical steel production can be expected, especially in the smaller European countries where crude steel production in blast furnaces is no longer economically feasible. In these cases, the share of electrical steel production may reach 100 % like in Denmark or Ireland in the year 2000 (see section 16.2.1).

The basic assumption made about crude steel production in European countries is that it declines after a peak due to the end of industrialisation and motorisation of a country. Therefore, Eastern European countries either exhibit a still growing or a stagnating pattern of steel production, while Western European countries all have declining trends in steel production in physical terms. However, as increasing amounts of steel scrap become available, these serve as secondary material for the electric arc process which shows increasing or stagnating trends. The overall result is that the per capita crude steel production is declining slightly in most EU-15 countries. However, in some Eastern European countries and Turkey, per capita production will continue to increase until 2030 (see Chapter 16.2.1).

Assumptions about the drivers of aluminium production in Europe

Aluminium is a young material compared to steel. Its specific weight is considerably less than steel which is the major reason it is often preferred to steel in mobile applications when lightweight solutions are necessary (e.g. airplanes, elevators, packaging, car wheels or even cars and windows). However, the production of primary aluminium is very electricity-intensive due to its electrolytic production process and it is also costly compared to steel. Therefore, aluminium is in stiff competition with steel as well with plastics, as plastics also have low specific weight and similar properties to aluminium (such as no corrosion, recyclable (polymers), and similar prices).

Aluminium can easily be recycled by melting aluminium scrap. Because of the high price per ton of primary aluminium (about 2,000 € / t), the production of secondary aluminium is very attractive and recycling a widespread practice. As aluminium is a young material, the share of secondary aluminium in total aluminium production should be rather low. Since primary aluminium is so electricity-intensive, much of it is produced in countries with cheap electricity (like Canada or Australia). Austria, the Baltic States, Belgium/Luxembourg, Bulgaria, Denmark, Finland, the Czech Republic, Ireland, Malta/Cyprus and Portugal do not have any *primary aluminium production*. Based on production in the year 2005, the development of primary aluminium production was estimated for EU27 (+ Norway, Switzerland, Turkey) applying the following basic considerations:

- Most of the increases in primary aluminium demand in Europe will be satisfied by imports from countries with cheap electricity.
- In many European countries, existing production capacities will be maintained (but not enlarged) and mostly re-invested (but not in Germany or in other European countries in cases of re-investments in the next decades).
- The production data between the estimated values for each decade were calculated as linear increases or decreases.

The primary aluminium production of France, Hungary, Romania and Spain remains constant after 2030 (see Chapter 16.2.1).

Assumptions about the drivers of cement production in Europe

Cement is an important construction material, not only for houses and buildings, but also for the transportation infrastructure of a country such as bridges, tunnels, roads or airports. This means that the development of a country's population, country size and topography and transportation infrastructure are major determinants when estimating the cement demand of an industrialised country. It also means that each industrialised country experiences a maximum cement demand per capita during its capital stock construction phase. This per capita cement demand decreases afterwards to a lower cement demand per capita for fully industrialised countries when only re-investments have to be made. This consideration implies that per capita estimates are the best method, assuming that cement is cheap to produce and expensive to transport over long distances so that changing trade patterns are unlikely in the future.

The relevant economic branch "non-metal minerals", simulated by the E3ME and the ASTRA models, shows moderate growth for the EU15 countries plus Norway and Switzerland and generally higher growth for Eastern European countries. Although the non-metal minerals cover many more industrial products than just cement (e.g. lime, bricks, glass (see Chapter 5.2.4) and ceramics), the economic development of this branch has been used as an indicator to differentiate the per capita estimates.

Based on the production of cement per capita in the year 2000, its development was estimated by country for the years 2020, 2030, 2040, and 2050 for EU27 (+ Norway, Switzerland, Turkey) (see Chapter 16.2.1).

Assumptions about the drivers of paper production in Europe

Paper is a natural material made from wood, recycled paper and additives. The average annual paper and board production grew by 3.3 % per year between 1980 and 1997 in Western Europe (Competitiveness Study of the European Pulp, Paper and Board Manufacturing Industry 1998, Confederation of European Paper Industries CEPI). This development was not actually expected by many experts in the 1990s as it was a widespread belief that the increasing use of computers and telecommunications would reduce the demand for paper in the near future. As paper production is quite energy- and resource-intensive, a new European declaration on paper recycling covers a total of 29 European countries and aims to ensure that the recycling rate reaches 66 % by 2010.

The paper production of the EU27 + Norway and Switzerland is calculated based on the following categories: production and net import of pulpwood (in metric tonnes), net import of pulp (in metric tonnes), insertion quotas of recycled paper (in %) and insertion quotas of additives (in metric tonnes). The following equation was used for paper production (see Equ. 5.2.1-1):

Production of paper =

(net import of wood pulp/pulp in tonnes
+ net import of pulpwood in tonnes
+ production of pulpwood in tonnes)
/ (1 – (additives in % of paper production
+ quotas of insertion of recycled paper in %)

Equation 5.2.1-1

The economic data of the E3ME and ASTRA models form the basis used to define the main development trend concerning the wood and paper sector. The development of different wood-classes therefore follows the progression of the E3ME-sector “wood and paper” from 2005 until 2030 as well as the ASTRA-sector “paper” from 2030 to 2050. It should be noted that the ASTRA-sector “paper” combines the two E3ME-sectors “wood and paper” and “printing and publishing”.

In the rich Western European countries, the elasticity factor - the relation between physical growth and economic growth - was selected as 40 % of the annual economic increase *from 2005 to 2030*. In some Eastern European countries (Estonia, Latvia, Lithuania, Slovakia, Slovenia, Bulgaria, Romania), the elasticity factor was estimated as 50 % between 2005 and 2030, because their industry sector “wood and paper” was assumed to grow faster. The remaining annual economic increase is not due to increasing physical paper production, but due to improved paper quality, wood products, and printing as well as publishing activities which all add to the growth in value added of the sector (Detailed results see Chapter 16.2.1).

Assumptions about the drivers of glass production in Europe

The glass industry is very heterogeneous, with a wide variety of products and applications (food industry, construction industry, beverage industry, automotive industry, etc.). But the glass industry in Europe only consists of a very limited number of companies. Where glass production is restricted to just two or three national manufacturers, production data are confidential. Therefore there are few publicly available statistics of glass production in Europe. Only global production figures by glass types are available at EU level.

Europe is the most mature glass market and has the highest proportion of value-added products (Pilkington). About 30 million tonnes of glass are produced here each year. Container glass represents the largest share (~ 61 %) followed by flat glass (~ 26 %) and other glass (~ 13 %). Germany is the biggest manufacturer of glass (~ 24 %) followed by France (~ 18 %) and Italy (17 %). In 2005, the glass industry was run at around 90 percent capacity utilisation, globally (Pilkington).

The European glass industry shows a stable development of production with a marginal increase (~1 % per year) over the last few years. In contrast, the glass demand of the various countries has grown more quickly than their GDP over the last 20 years (Pilkington). Furthermore, the demand for value-added products is growing at a faster rate than the demand for basic glass.

The basic data defining the development of production in the glass sector are economic production data from the E3ME and ASTRA models, i.e. the development of the different glass categories (flat glass, container glass, other glass) follow the progression of the E3ME-sector “non-metallic mineral products” from 2005 until 2030 and of the ASTRA-sector “non-metallic mineral products” from 2030 to 2050.

In most Western European countries (Austria, Belgium/Luxembourg, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Sweden, United Kingdom, Norway and Switzerland), the elasticity between physical and economic growth is 40 % of the annual economic increase from 2005 to 2030. In the poorer Western and Central European countries (Greece, Portugal, Spain, the Czech Republic, the Baltic States, Hungary, Poland, Slovakia, Slovenia, Bulgaria and Romania), the elasticity was estimated to be 50 % of the annual economic increase from 2005 until 2030 because the share of high value-added products in production is assumed to be lower and because there is a substantial demand for glass due to the increasing consumption of private households, investments in buildings and retrofitting windows. Since 1992, the average glass production growth in Turkey has been 5 % per year. Therefore the glass industry in Turkey is estimated to increase by 3 % from 2005 to 2030. Subsequently, in the years 2030 – 2050, glass production growth is assumed to decline to 2 % per year. There is no glass production in Malta or Cyprus (Detailed assumptions see chapter 16.2.1)

5.2.1.2 Assumptions about material efficiency in the 2°C Scenario – 2000 to 2050

Compared to the Reference Scenario, improved material efficiency and substitution of energy-intensive materials is assumed for all industry sectors in the 2°C Scenario. From 2000 to 2009, the Reference Scenario and the 2°C Scenario have identical production results in the basic product industry sectors. From 2010 to 2050, production changes take place in energy-intensive products due to the assumed high energy prices (including energy taxes and emission certificates, see Chapter 4) and climate change policies that include material efficiency and substitution policies at national and at EU level, as well as in most other parts of the world. Similar technological improvements are estimated for all the European countries so that production changes are calculated using the same factors for all these countries.

Assumptions about the drivers of steel production in Europe

Crude steel production, which includes electrical as well as oxygen steel, decreases in this scenario until 2050 in comparison to the Reference Scenario due to improved material efficiency and increased material substitution. Due to specific technical applications, the production of oxygen steel will not decline as much as electrical steel in the next 40 years (Table 5-3).

Table 5-3: Production changes (in %) of electrical and oxygen steel in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
Energy-intensive product	Production changes in % per year compared to Reference Scenario				
Electrical steel	0.0	- 0.5	- 0.6		
Oxygen steel	0.0	- 0.3	- 0.4	- 0.5	

Source: BSR Sustainability GmbH

Assumptions about the drivers of aluminium production in Europe

In line with the assumptions about the drivers of steel production, primary and secondary aluminium production is also assumed to fall continuously in the future (see Table 5-4).

Table 5-4: Production changes (in %) of aluminium in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

	2000-2010	**2010-2020**	**2020-2030**	**2030-2040**	**2040-2050**
Energy-intensive product	Production changes in % per year compared to Reference Scenario				
Primary aluminium	0.0	- 0.2		- 0.3	
Secondary aluminium	0.0	- 0.2		- 0.3	

Source: BSR Sustainability GmbH

Assumptions about the drivers of cement production in Europe

Similar to steel and aluminium production, cement production is assumed to decrease continuously in the future due to technological innovations and a global economic slowdown (see Table 5-5).

Table 5-5: Production changes (in %) of cement in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

	2000-2010	**2010-2020**	**2020-2030**	**2030-2040**	**2040-2050**
Energy-intensive product	Production changes in % per year compared to Reference Scenario				
Cement	0.0	- 0.5			

Source: BSR Sustainability GmbH

Assumptions about the drivers of paper production in Europe

Paper production in the 2°C Scenario is also reduced by between 0.5 % and 0.7 % per year in all European countries compared to the Reference Scenario (see Table 5-6). This development is due to the “paperless office” and technological innovations (like thin and flexible displays for books or newspapers, thinner paper types, etc.). The percentage of recycled paper does not change compared to the Reference Scenario.

Table 5-6: Production changes of paper (in %) in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

	2000-2010	**2010-2020**	**2020-2030**	**2030-2040**	**2040-2050**
Energy-intensive product	Production changes in % per year compared to Reference Scenario				
Paper	0.0	- 0.5	- 0.6	- 0.7	

Source: BSR Sustainability GmbH

Assumptions about the drivers of glass production in Europe

The glass production of other glass is identical to the results of the Reference Scenario. In contrast, container glass production is estimated to decrease by roughly -0.5 % to -1.0 % per year (see Table 5-7). For the same period, there is an increased production of flat glass compared with the Reference Scenario. This increase is due to rapidly growing photovoltaic cell production, window glass (for example triple glazing) and the demand of the automobile industry.

Table 5-7: Production changes of glass (in %) in EU27 + Norway, Switzerland and Turkey compared to the Reference Scenario, 2000 – 2050

	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
Energy-intensive product	Production changes in % per year compared to Reference Scenario				
Container glass	0.0	- 0.5	- 0.8	- 1.0	
Other glass	0.0				

	2000 -2010	2010 - 2013	2014 - 2020	2020 - 2026	2026 - 2036	2036 - 2048	2048 - 2050
	Production changes in % per year compared to Reference Scenario						
Flat glass	0.0	+ 1.3	+ 1.2	+ 1.1	+ 1.0	+ 0.9	+ 0.8

Source: BSR Sustainability GmbH

5.2.2 Production changes in energy-intensive products

5.2.2.1 Reference Scenario – 2000 to 2050

Results for steel production in European countries – 2000 to 2050

The total crude steel production of EU27 plus Switzerland and Norway increases slightly from 195 Mt to 200 Mt, before slowly decreasing to about 191 Mt in 2030 (see Table 5-8). The decreasing population between 2030 and 2050 (-4.5 %) and increasing net imports of investment goods with steel components together have the effect of reducing crude steel production to 174 Mt in 2050, i.e. a drop of 9 % over two decades. If Turkey's steel production is included, the peak in steel production is postponed to 2030, and production in 2050 is about 11 Mt higher than in 2000 (i.e. +5.5 %; see Table 16-10).

Relative to the gross production of the basic metal industry, which stagnates until 2030, the estimates of crude steel production do not contradict the economic development of the larger economic sector (basic metals).

The development of *electrical steel* is more dynamic due to the basic assumption of increasing steel scrap. The electrical steel produced in EU27 plus Switzerland and Norway increases from around 80 Mt in 2000 to 95 Mt in 2050, i.e. by 19 % (see Table 16-11). This raises the share of electrical steel in total crude steel production from 41.3 % in 2000 to almost 55 % in 2050.

The trends are similar even if Turkish steel production is included. However, the trend is then more pronounced. The share of electrical steel in total crude steel production increases from 82 Mt (or by 39.4 %) in 2000 to 115 Mt in 2050 (i.e. by 52.4 %). This equals an average annual growth of almost 0.7 % per year.

Table 5-8: Production of crude steel (oxygen steel + electrical steel) in Europe in 1000 tonnes, Reference Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU27 + 2	Oxygen steel	121,370	121,110	113,370	104,340	81,620
	Electrical steel	73,280	78,330	82,730	87,090	92,980
	Crude steel (oxygen steel + electrical steel)	**195,140**	**200,110**	**196,430**	**191,400**	**174,720**
Total Europe	Oxygen steel	126,600	133,230	133,960	133,840	107,550
	Electrical steel	82,370	93,780	99,130	104,500	112,600
	Crude steel (oxygen steel + electrical steel)	**209,470**	**227,670**	**233,430**	**238,300**	**220,270**

Source: BSR Sustainability GmbH

Results for aluminium production in European countries – 2000 to 2050

The total production of primary aluminium increases from 4 Mt in 2000 to 6.1 Mt in 2050 (+52 %) due to substantial production increases in Norway and small increases in the UK, some central European countries, and Turkey. Including Turkey does not significantly alter the figures of total European primary aluminium production (to 6.2 Mt in 2050, seeTable 16-12).

The total production of secondary aluminium increases at a slightly faster rate than that of primary aluminium, reaching more than 4.1 Mt in 2050 (see Table 16-13). Starting from initial low values per capita, the highest growth is in Central European countries due to the expected modernisation of the capital stock here and also some shifting of production sites from Western to Central Europe. Looking at both types of aluminium, production increases significantly by more than 50 % from 2.7 Mt to slightly above 10 Mt (see Table 5-9).

Table 5-9: Total production of aluminium (primary + secondary) in Europe in 1000 tonnes, Reference Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU-27 + 2	Primary aluminium	4,020	4,900	5,290	5,650	6,130
	Secondary aluminium	2,670	2,970	3,320	3,660	4,120
	Total aluminium	**6,690**	**7,870**	**8,610**	**9,310**	**10,250**
Total Europe	Primary aluminium	4,090	4,960	5,350	5,720	6,220
	Secondary aluminium	not specified	not specified	3,370	3,720	4,200
	Total aluminium	not specified	not specified	**8,720**	**9,440**	**10,420**

Source: BSR Sustainability GmbH

Results for cement production in European countries – 2000 to 2050

The total cement production of Europe is almost constant at around 240 Mt per year, but the long-term trend is a declining one: Cement production is reduced to 203 Mt in 2050. This decline reflects the basic influence of population and the assumption that rich, industrialised countries have completed their building stock and infrastructure and only need cement for re-investments. Major contributions to the drop in cement production between 2000 and 2050 are from Italy (-12.8 Mt), Spain (-15.2 Mt), and Greece (-10.2 Mt). If Turkey is included, European cement production stagnates one decade later, before also declining to 244 Mt in 2050, or by -12 % relative to the year 2000 (see Table 16-14).

Results for paper production in European countries – 2000 to 2050

The data of this sector are subject to further revision after 2030 as the economic data of ASTRA have been re-calculated which was not able to be reflected in the figures of Table 16-15. Total paper production in Europe increases from 93.3 Mt in 2000 to 134 Mt in 2030 (or by almost 44 % or 1.2 % per year). In the last two decades, paper production totals 158 Mt, i.e. slows down to an annual increase of 0.8 %, which still represents a substantial per capita growth of almost 1.2 % per year in the light of the shrinking population.

Results for glass production in European countries – 2000 to 2050

The total glass production of Europe increases from 35 Mt in 2000 to 43.2 Mt in 2030 (or by almost 23.4 % or 0.7 % per year (see Table 16-16). In the final two decades, glass production reaches more than 47 Mt and production slows to an annual increase of 0.4 %, which still represents a significant per capita growth of 0.65 % per year in the light of the shrinking population. If the Turkish glass industry is included, the increase in glass production is more pronounced, starting from 36.6 Mt and growing by almost 0.9 % per year to 47.3 Mt in 2003 and to 53 Mt in 2050 (i.e. by 0.57 % per year).

5.2.2.2 2°C Scenario - 2000 to 2050

Results for steel production in European countries – 2000 to 2050

The total crude steel production of EU27 plus Switzerland and Norway increases slightly in the 2°C Scenario from 195 Mt to about 199 Mt in 2010, before slowly decreasing to about 138 Mt in 2050 (see Table 5-10). Electrical steel production of EU27 plus Switzerland and Norway decreases only slightly in the 2°C Scenario from around 73 Mt in 2000 to 71 Mt in 2050 (see Table 16-18). Therefore, the share of electrical steel (EU27 + 2) in total crude steel production rises from 38 % in 2000 to 51 % in 2050 (see Table 16-17). Over the same time, the oxygen steel produced decreases from 121 Mt to 67 Mt (~-49 %). The total amount of crude steel production in EU27+2 in 2010 is only 1.4 Mt lower than in the Reference Scenario. The difference between the Reference and the 2°C Scenario concerning the amount of produced crude steel increases to 36 Mt in 2050 or from 0.4 Mt (2010) up to 21 Mt (2050) for electrical steel.

Table 5-10: Production of crude steel (oxygen steel + electrical steel) in Europe in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU27 + 2	Oxygen steel	121,370	120,750	109,510	96,510	67,340
	Electrical steel	73,280	77,940	78,100	76,990	71,040
	Crude steel (oxygen steel + electrical steel)	195,140	198,690	187,610	173,500	138,380
Total Europe	Oxygen steel	126,600	132,830	129,410	123,800	88,730
	Electrical steel	82,370	93,310	93,580	92,380	86,030
	Crude steel (oxygen steel + electrical steel)	209,460	226,140	222,980	216,180	174,750

Source: BSR Sustainability GmbH

Results for aluminium production in European countries – 2000 to 2050

The total production of primary aluminium increases from 4 Mt in 2000 to 5.4 Mt in 2050 (see Table 16-19). In contrast to the Reference Scenario, this means a decline of about 11.4 % for EU27+2 in the year 2050. In comparison, the total production of secondary aluminium increases, starting at 2.7 Mt in 2000 and reaching 3.7 Mt in 2050 (see Table 16-20). In the same period, the total amount of aluminium produced in EU27+2 increases from 6.69 Mt in 2000 up to 9.13 Mt in 2050 (see Table 5-11).

Table 5-11: Production of aluminium (primary aluminium + secondary aluminium) in Europe in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country group	Production of	2000	2010	2020	2030	2050
EU27 + 2	Primary aluminium	4,020	4,890	5,170	5,350	5,430
	Secondary aluminium	2,670	2,960	3,250	3,510	3,700
	Total aluminium	**6,690**	**7,850**	**8,420**	**8,860**	**9,130**
Total Europe	Primary aluminium	4,090	4,950	5,230	5,420	5,510
	Secondary aluminium	not specified	not specified	3,290	3,570	3,770
	Total aluminium	not specified	not specified	**8,520**	**8,990**	**9,280**

Source: BSR Sustainability GmbH

Results for cement production in European countries – 2000 to 2050

In the 2°C Scenario, a substantial decrease in European cement production is assumed due to several factors: the stagnation or sometimes even decreasing per capita cement consumption, which already results in a decrease of almost 40 Mt by 2050 in the Reference Scenario. This decreases further by almost 42 Mt in the EU27+2 due to better design of buildings and built infrastructures, substitution by other construction materials such as metals, bricks, and wood, and higher cement quality. In total, EU27+2 countries produce 190 Mt cement in 2035 and only 162 Mt in 2050. Even in Turkey and some other EU countries, cement production starts declining after 2020 (see Table 16-21).

Results for paper production in European countries – 2000 to 2050

While in the Reference Scenario, paper production increased steadily over the whole period, in the 2°C Scenario, European paper policies induce a lower growth in paper demand, saving 10 Mt in 2020 and up to 90 Mt in 2050. This reduction is assumed to be achieved by lighter paper, new paper, paper substitution (including modern communication systems), and a more efficient packaging and copying use of paper in offices (front and back page). In total, this leads to a stagnation of paper production at around 118 Mt in Europe after 2035, which substantially reduces the energy demand for this energy-intensive product (see Table 16-22).

Results for total glass production in European countries – 2000 to 2050

The demand and related domestic production of glass is quite complex, because two complementary developments have to be taken into account. On the one hand, there are additional efficiencies in glass use and glass substitution (e.g. by plastics). On the other hand, there is increasing production of double and triple glazing for low energy and passive buildings in the 2°C Scenario leading to quite substantial differences among countries between the Reference and the 2°C Scenario. This is why total glass production in Europe stagnates at around 2030 after an increase of 15% relative to 2005 (see Table 16-23). However, there are important structural changes in European countries: The new member states and some Western European countries which had low building standards in the past have small reductions in glass production, while southern European countries experience a reduction in total glass production of between 20 and 25%.

5.2.3 Remarks on data availability

There are marked differences in the availability of production output data in the various industry sectors.

The available database of the cement industry is relatively widespread. Historical data (including export and import data) for the countries are present in different databases. The oldest accessible data for cement production are from the year 1913 (World statistical review N°18, Cembureau). Current key factors of the cement industry sector are also available (Word Statistical Review (Annual), Cembureau). Useful sources for cement data were: The European Cement Association (CEMBUREAU), national federations (e.g. Verein Deutscher Zementwerke e.V. [VDZ], Bundesverband der deutschen Zementindustrie e.V. (BDZ), FEBELCEM, etc.) and national/international statistical offices (Eurostat, Destatis, etc.).

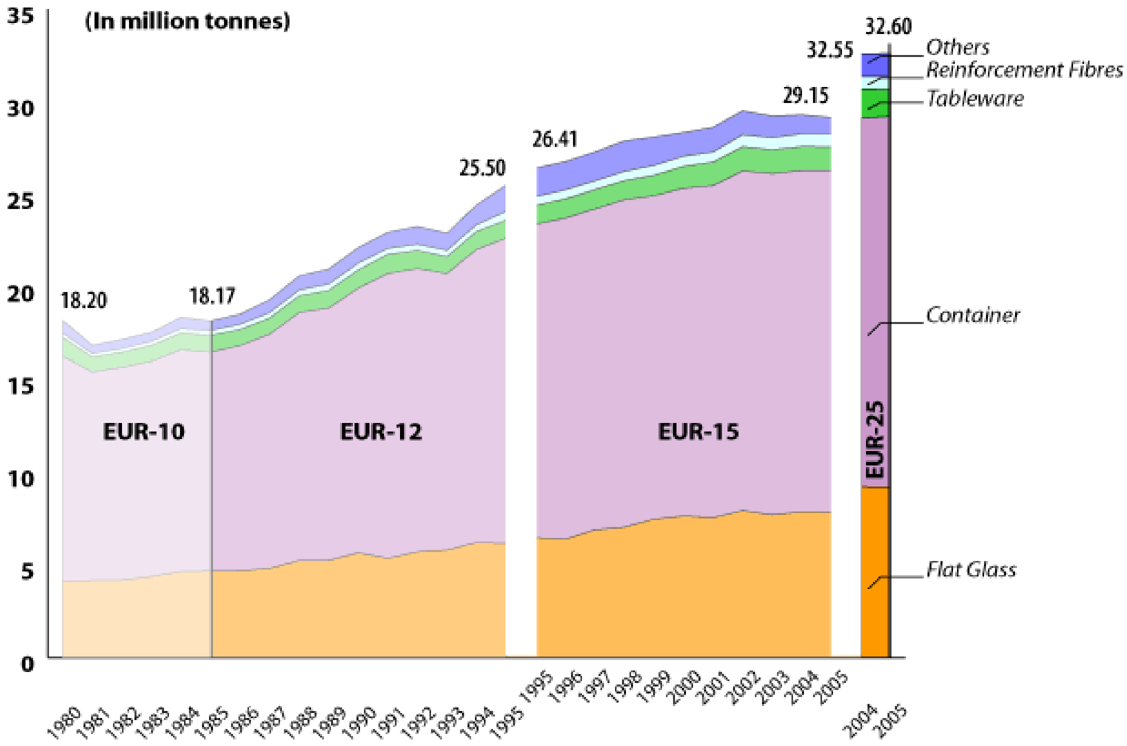
The availability of production data for the aluminium industry, the steel industry and the paper industry is also satisfactory. The Statistical Yearbooks of the Steel Industry and the Metallstatistik/Metal Statistics (World Bureau of Metal Statistics) are common benchmarks for metals, which contain data for most western and eastern European countries. These sources can be used as annual reports or taken from the Internet (e.g. US Geological Survey, USGS).

For the paper sector, the Verband Deutscher Papierfabriken e.V. (VDP), the Confederation of European paper industries (CEPI), Eurostat and the statistical database FAOSTAT of the food and agriculture organisation of the United Nations provide the best data.

In contrast to the sectors mentioned above, the glass sector and the wood sector have the poorest data availability. The glass production data are compiled from national sources (statistical offices, associations of the glass industry), annual reviews of companies, press releases, the Internet, glass market studies (e.g. Overview of Glass Container Production in the EU: 2006, British Glass), the Standing Committee of the European Glass Industries (CPIV) and the European Federation of Glass Packaging.

As already stated in the section "Assumptions on the drivers of glass production in Europe", the glass industry is very heterogeneous with a wide variety of products and applications (food industry, building industry, beverage industry, automotive industry, etc.). In addition there are problems with data confidentiality. Therefore the available statistics on glass production in Europe are very sparse. Production figures by glass types are only available at EU level (see Figure 5-3). Production data for most eastern European countries are very difficult to find.

The wood sector covers wood production for material utilisation (industrial wood) as well as wood production for energy use. But a large proportion of the wood produced is used privately by forest owners without any records. Therefore official statistics of "wood cuttings" do not feature the real amount of wood used. Furthermore the wood sector, which is not well organised, is subdivided into different industrial sectors and various categories of wood utilisations. In particular, there are not many subdivided statistics available for fuelwood (firewood, woodchips and wood pellets; see also section 5.3).



Source: The Standing Committee of the European Glass Industries

Figure 5-3: EU glass production 1980 to 2005

5.3 Wood fuel demand in Europe in the Reference and 2°C Scenario, 2000 to 2050

The MATEFF model also calculates the availability of wood fuels by receiving the figures of available round wood calculated by the EFISCEN model, taking the projections of the Paper demand and production from the MATEFF model, considering in addition the wood demand for the wooden products manufacturing and also the available waste wood from construction, saw dust and other wooden wastes. From this data, the total available wooden material as a potential for wood fuel is derived and can be used for projections of the potential for modern forms of wood use (e.g. chips and pellets). This method has been described in detail in Jochem et al. (2007).

5.3.1 The Reference Scenario

As the results of the EFISCEN model (see Chapter 5.1.2.1) show, there is slightly more roundwood available (including forest residues such as top wood or branches) in Europe in the Reference Scenario (+9.4 %) than in the Base Case Scenario. this is due to higher average temperatures and more precipitation north of the Alps. However, these changes are not uniform for total Europe, as there are favourable conditions for forests north of the Alps, but their growth is impeded south of the Alps due to diminished precipitation.

5.3.1.1 Assumptions on the Reference Scenario

There are considerable differences regarding roundwood availability (including forest residues) between countries north of the Alps and countries south of the Alps. In the Reference Case, the South-Alps region has less biomass available than the North-Alps region, because drier periods on the one hand and more irregular rainfall on the other hand are expected in this area. No changes are assumed for waste wood availability and wood-based products. There are also no different assumptions for fuel wood for cogeneration and district heating plants in the Reference Case. From 2000-2010, the data for the Reference Scenario in all sectors are taken from the Base Case Scenario. The general trend of the South-Alps region compared with the North-Alps region shows less biomass development (see Table 5-12).

Based on these assumptions, the Mateff model distinguishes between two regions for the calculations of fuelwood in Europe: South of the Alps and North of the Alps. Calculations and projections were made for both regions which are described below

Table 5-12: Roundwood availability in EU27 (including forest residues), Reference Scenario, 2005 - 2050

Country group	Roundwood availability in PJ								Difference to Base Case in %		
	Base	**Ref.**	**Base**	**Ref.**	**Base**	**Ref.**	**Base**	**Ref.**			
	2005		2020		2030		2050		2020	2030	2050
N. Alps	3,374	3,374	4,396	4,409	5,131	5,188	5,333	6,023	+0.3	+1.1	+13
S. Alps	1,106	1,106	1,287	1,279	1,510	1,503	1,960	1,954	-0.6	-0.4	-0.3
EU27+2	**4,479**	**4,479**	**5,683**	**5,688**	**6,641**	**6,691**	**7,293**	**7,977**	**+0.1**	**+0.8**	**+9.4**

Note: South Alps countries: Bulgaria, France, Greece, Hungary, Italy, Portugal, Romania, Slovenia, Malta, Cyprus and Spain

Source: Efiscen, FAO 2008, own calculations

Countries south of the Alps

In the Reference Scenario, the countries further south of the Alps (Bulgaria, France, Greece, Hungary, Italy, Portugal, Romania, Slovenia, Malta, Cyprus and Spain) are forecasted to have a little less biomass than in the Base Case Scenario (-1.3% until 2050), because they are likely to be drier and experience more heavy rainfalls, but with less water available due to dried out soils. Based on these assumptions, the availability for woodchips directly from the forest (70 % of the woodchips) and firewood directly from the forests (80 % of the firewood) is assumed to decrease by 4% per year and country from 2011 onwards in private households, services, agriculture, district heating, co-generation and industry sectors as the demand of wood for construction and paper does not change in the Reference Scenario. However, this declining availability of fuel wood coincides with warmer temperatures and less heating demand (see Chapter 6.3 and 6.5).

Countries north of the Alps

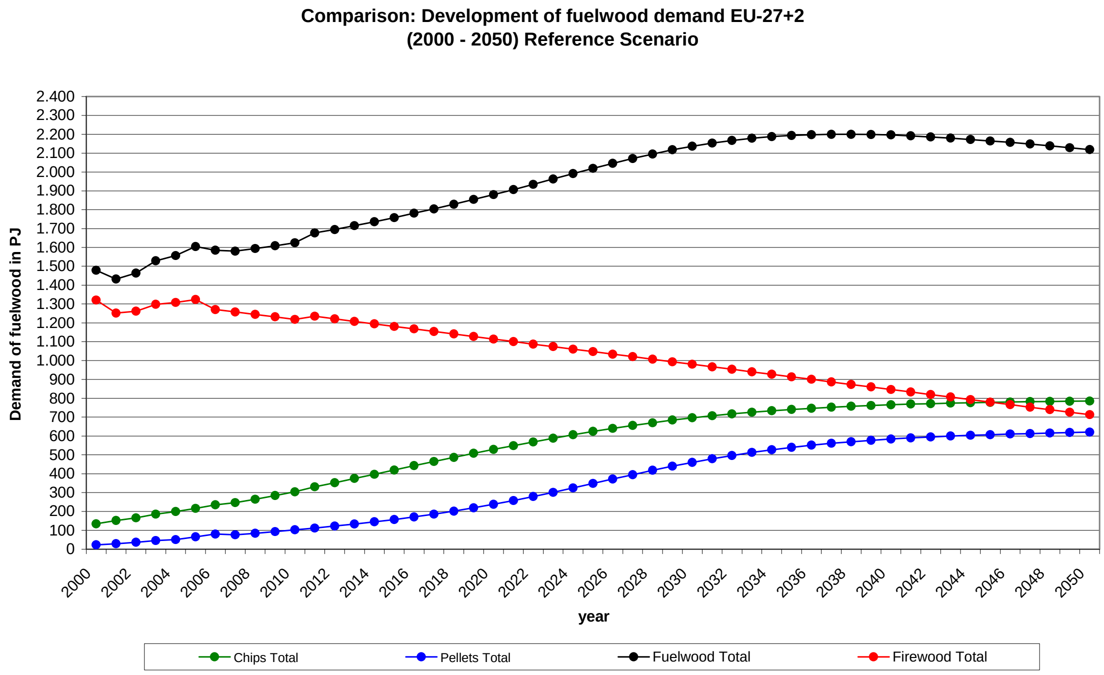
The situation in the countries further north of the Alps (Austria, the Baltic, Belgium, Luxemburg, Czech Republic, Denmark, Finland, Germany, Ireland, Netherlands, Norway, Poland, Slovakia, Sweden, United Kingdom and Switzerland) is predicted to develop contrary to the development in the South, i.e. an increase in biomass. More wood is available than in the Base Case Scenario (+13%), because more biomass can grow in these countries due to warmer temperatures and advantageous growing conditions. The availability for woodchips and firewood is predicted to increase by almost of 4% per year and country from 2011 onwards in private households, services, agriculture, district heating, co-generation and industry.

5.3.1.2 Results of the Reference Scenario

Comparison firewood, pellets and chips demand

Contrary to the differences between the regions north and south of the Alps the EFISCEN model calculated for the total roundwood availability in EU27+2 (+9% in 2050 relative to the Base Case Scenario), total wood supply of the Reference Scenario (including wood wastes and landscape wood) available for fuelwood use in non-grid connected firing plants appears quite similar to the Base Case Scenario. The overall picture shows an increase in total fuelwood to a maximum of 2200 PJ in 2038 (see Table 5-13).

There may be a small unused potential due to some not implemented measures of sustainable forest management in some European countries. In 2050, total fuelwood amounts to about 2120 PJ in EU27+2. Looking at the Reference Scenario in more detail, it becomes obvious that woodchips substituting the firewood use pass the break even point in Europe around 2045 onwards. Woodchips from short rotation crops, such as already exist in Portugal, Sweden or Spain, can also displace conventional firewood (see Figure 5-4).



Source: BSR-Sustainability 2008

Figure 5-4: Share of firewood and new forms of fuelwood, EU27+2, Reference Scenario, 2000 to 2050

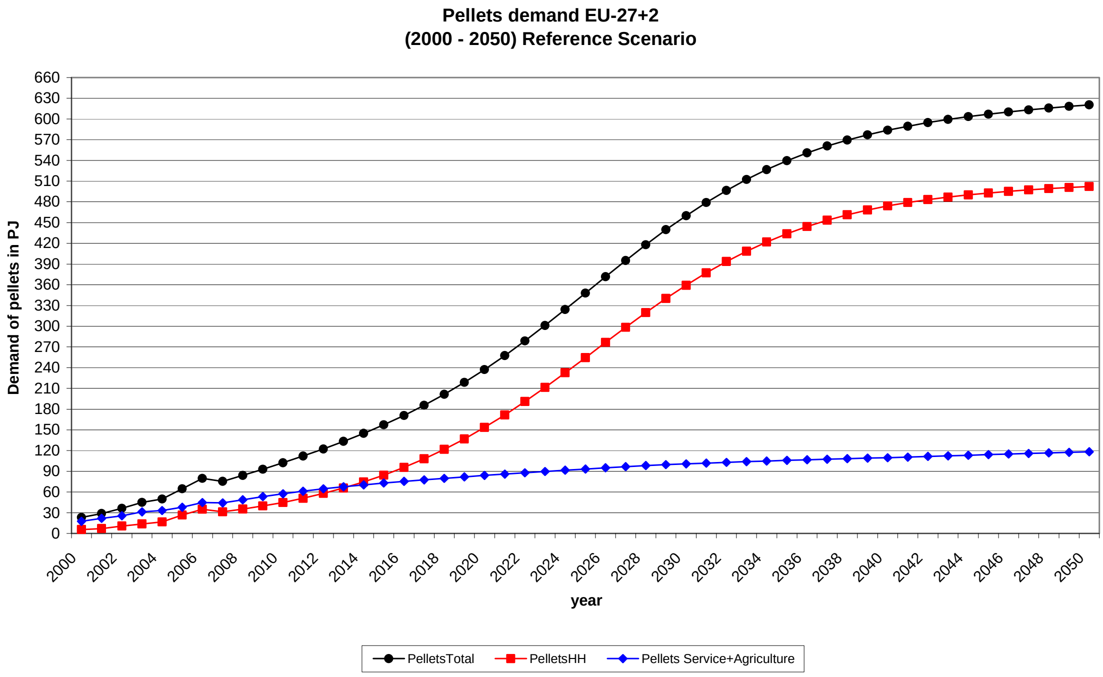
The different kinds of fuelwood in detail

The detailed calculations of the different kinds of fuelwood - pellets, chips and firewood - are similar to the data in the Base Case Scenario. The Reference Scenario does not consider policy changes, so there are no differences in pellet demand to the Base Case Scenario, because pellets are mainly produced from sawdust and it is quite inefficient to produce pellets from fresh roundwood. Similar to the Base Case, pellet demand in 2050 is considered to increase up to 620 PJ in total (see Figure 5-5).

Table 5-13: Fuelwood demand in EU27+2 in the Reference Scenario

Country group	Fuelwood demand in PJ								Difference to Base Case in %		
	Base Case	Reference Scenario	Base Case	Reference Case	Base Case	Reference Scenario	Base Case	Reference Case			
	2005		2020		2030		2050		2020	2030	2050
North-Alps	1,189	1,189	1,409	1,447	1,582	1,621	1,548	1,582	+2.7	+2.4	+2.2
South-Alps	416	416	433	432	517	515	537	535	-0.2	-0.2	-0.3
EU27+2	**1,605**	**1,605**	**1,842**	**1,879**	**2,098**	**2,136**	**2,085**	**2,118**	**+2.0**	**+1.8**	**+1.6**

Source: BSR-Sustainability 2008



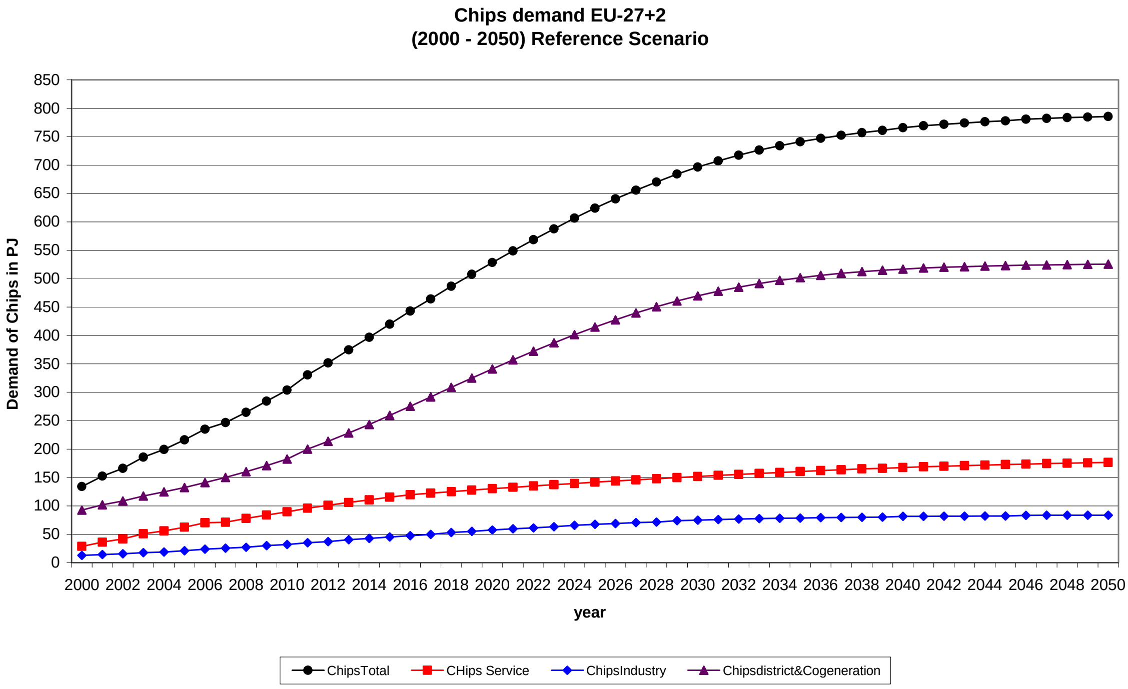
Source: BSR-Sustainability 2008

Figure 5-5: Pellet demand (EU 27+2) in different sectors, 4° C Scenario, 2000-2050

Contrary to pellets, there is a higher increase in woodchip demand in EU27+2 in the Reference Scenario than in the Base Case Scenario, because more wood biomass is available and more wood can be used efficiently as chips either directly from the forest or from short rotation crops. There is an almost continuous increase in woodchip demand in the Reference

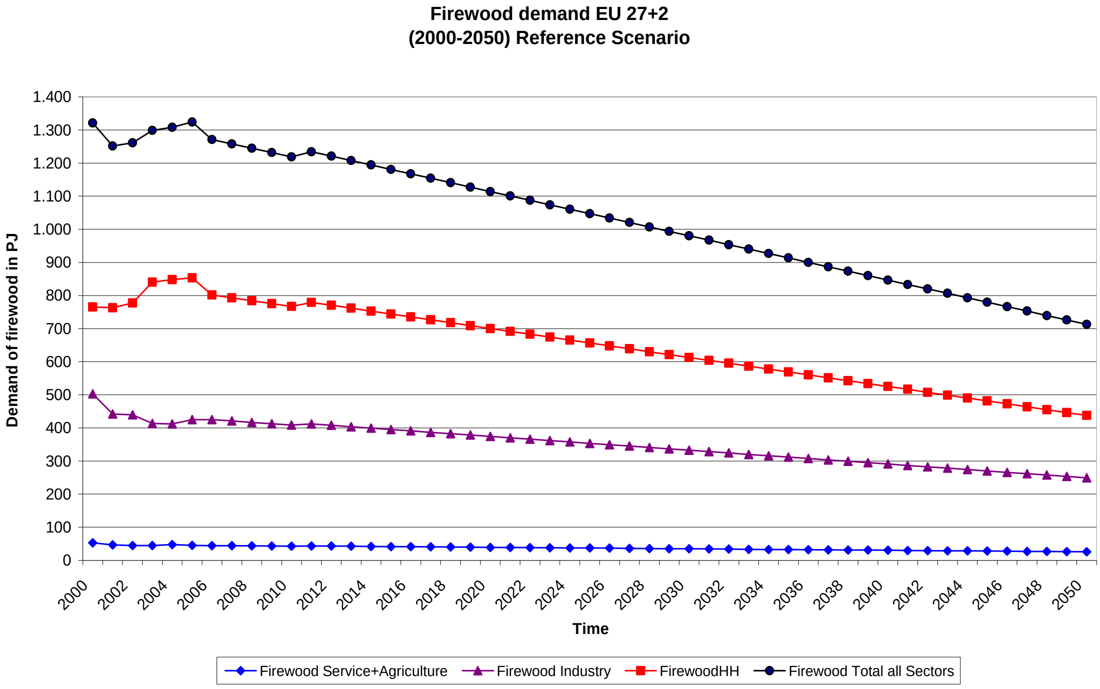
Scenario in Europe (EU27+2). Woodchips are mainly used in district heating plants, co-generation and industry. Total woodchip demand in 2050 is predicted to rise to 785 PJ (see Figure 5-6).

In the Reference Scenario, the firewood demand in Europe decreases by 46 % between 2000 and 2050 from around 1,320°PJ in 2000 to 710°PJ in 2050 (see Figure 5-7) which is essentially the same as in the Base Case Scenario. This means that the slightly higher biomass availability has no influence on firewood demand. The main share of this firewood is used in boilers, particularly in private households and farms outside of the cities, and also in boilers and wood gasification plants, particularly in industry and district heat plants.



Source: BSR-Sustainability 2008

Figure 5-6: Woodchip demand (EU27+2) by sectors, Reference Scenario, 2000 to 2050



Source: BSR-Sustainability 2008

Figure 5-7: Firewood demand of EU27+2 by sectors, Reference Scenario, 2000-2050

5.3.2 The 2°C Scenario

In the 2°C Scenario, the same distinction is made as in the Reference Scenario between the regions North-Alps and South-Alps for the projections of fuelwood. In addition to the relatively small changes in wood supply due to lower temperatures, the 2°C Scenario also assumes major policy changes and technical improvements; this leads to greater use of pellets and woodchips in all sectors, industry, co-generation and heating plants. For the first decade (2000-2010), however, the data for the 2°C Scenario remain the same as projected for the Base Case Scenario for all sectors because the changed policies do not have an effect before the second decade.

5.3.2.1 Assumptions of the 2° C Scenario

Based on the 2°C Scenario, the projections made by the MATEFF model include (small) changes in the growth of European forests and (major) policy changes as two factors of influence on the future use of fuelwood in Europe.

Natural changes in European forests

In the 2° Scenario, the countries south of the Alps (Bulgaria, Greece, Hungary, Italy, Portugal, Romania, Slovenia, Malta, Cyprus and Spain) are forecasted to have slightly less biomass than in the Base Case Scenario, because they are likely to have a drier climate with drier soils than in the Base Case Scenario. Fewer fellings are expected from forests in these countries compared to the Base Case Scenario. This is reflected in a slightly smaller production of woodchips and firewood directly from forests by some 1 % per year starting in 2011. This slight decline affects every sector: private households and services, the agricultural sector, district heating and co-generation plants as well as industry in the countries south of the Alps.

As the forests north of the Alps benefit from climate change in the 2°C Scenario, the projections for this part of Europe assume slightly higher biomass production compared to the Base Case Scenario. The production potential of woodchips and firewood stemming directly from the forest is predicted to increase by about 1 % yearly in all the sectors mentioned above.

Policy changes and technical improvements

In the 2° Scenario, changing polices will lead to greater use of renewable energies – therefore, there will be an increase in overall fuelwood demand in Europe. A substantial increase in the use of pellets and chips is expected in all European countries except Greece, Malta and Cyprus due to the reduced wood availability here in the 2°C Scenario. Almost stagnating demand is assumed in the Mediterranean countries, because these countries have low amounts of wood available from their forests, but high potentials for solar energy using solar thermal collector systems. Pellet use in private households and the service sector will almost stagnate relative to the Base Case Scenario as less wood availability from forests is compensated by more use of demolition wood and industrials waste wood.

In countries north of the Alps, changing policies will lead to increased pellet use due to increased mobilisation of demolition wood and short rotation crops; this will also increase the use of fuel wood in co-generation, industry and district heating. The pellet demand in industry, district heating and co-generation is calculated based on the woodchip development in the service sector in the Base Case Scenario. Starting in 2011, the chips data of the Base Case Scenario are increased annually by 1 % in the service sector of each country. The service sector is used because its chip use in the Base Case Scenario is expected to develop in a similar way to industrial pellet demand and the use of pellets in co-generation.

In addition, technical improvements in industrial wood use lead to more wood being available as wood fuel. For instance, more wood fuel is available because of the drop in the demand for wood due to highly efficient paper production technologies. Moreover, the resulting fresh wood available can be efficiently turned into woodchips. This is assumed to trigger a 3%

annual increase in the demand for woodchips in industry, district heat and cogeneration in each country north of the Alps in the 2°C Scenario.

5.3.2.2 Results 2°C Scenario: firewood, pellet and chip demand

In the 2°C Scenario, there is a sharp drop in the use of conventional firewood. In contrast, woodchips and pellets show increasing market shares, because the changes in policies support new forms of fuelwood and because modern automatic fuelwood plants and improved efficiencies in industrial wood use increase the amount of wood available for energy use. Pellets and chips can easily be delivered by van (similar to oil) and their energy density is higher than firewood, which has different economic advantages, (see Table 5-14).

Table 5-14: Gross calorific value of different kinds of wood (in kWh/kg)

Firewood		Pellets	Wood briquettes	Woodchips	
Conifer	Deciduous			dry G30 (water content < 20%)	damp G50 (water content ~ 50%)
4.3	4.2	4.7-5	5	4	2

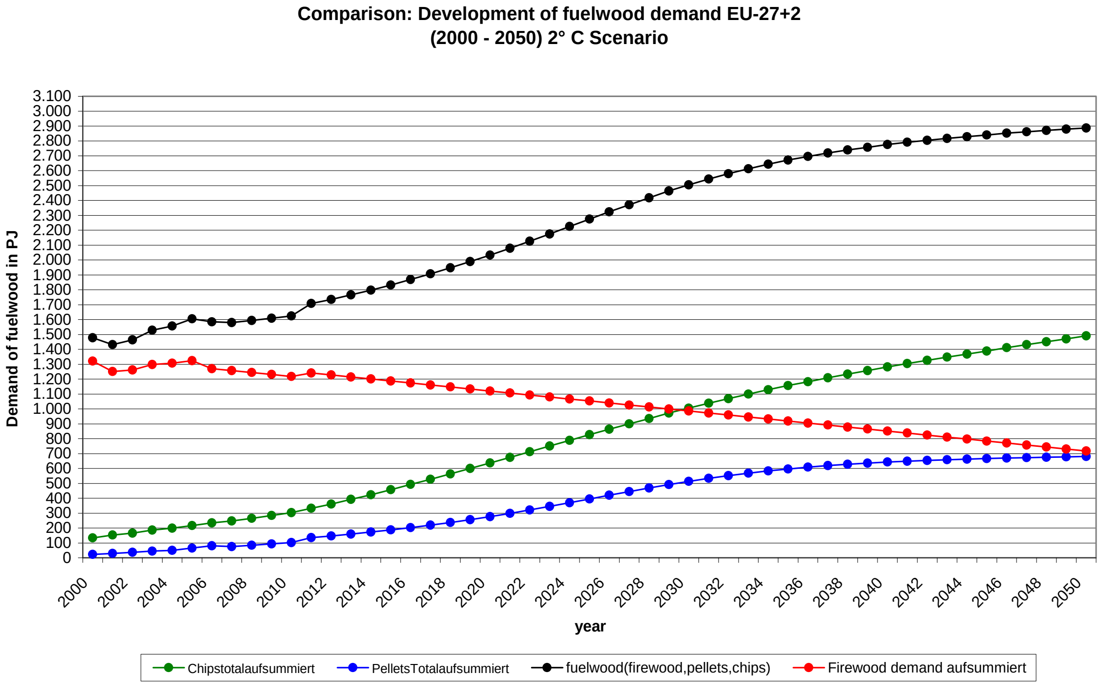
Source: BSR-Sustainability 2008

Compared to the Base Case Scenario, wood fuel demand in the 2°C Scenario is high (see Table 5-15). By the year 2005, the use of fuelwood peaks at a maximum of around 2,890 PJ. By 2030, the demand for firewood drops to 990 PJ which is lower than the demand for woodchips (around 1,000 PJ). In 2050, the pellets demand almost reaches with around 680 PJ the traditional firewood use with around 710 PJ (see Figure 5-8).

Table 5-15: Total fuelwood demand (firewood, wood pellets, woodchips), all sectors in EU-27 + 2 in PJ – Comparison of the Base Case Scenario and the 2 °C Scenario, 2015 – 2050

Country or country group	2015		2020		2030		2050	
	Base Case	2 °C Scenario	Base Case	2 °C Scenario	Base Case	2 °C Scenario	Base Case	2 °C Scenario
Austria	113	115	123	129	141	160	137	178
Baltic States	94	99	95	103	96	111	89	117
Belgium/Luxembourg	24	25	27	29	32	40	34	52
Bulgaria	27	27	26	26	27	29	25	31
Czech Republic	48	49	50	53	55	62	52	68
Denmark	20	21	21	22	21	24	22	26
Finland	218	229	219	238	209	244	171	237
France	72	73	85	88	142	149	161	175
Germany	263	284	311	358	375	480	350	550
Greece	9	9	10	9	13	13	17	18
Hungary	22	22	22	23	27	30	32	40
Ireland	9	9	11	12	17	21	22	32
Italy	72	79	79	89	87	103	86	114
Malta/Cyprus	0	0	0.0	0	0.0	0	0.1	0
Netherlands	7	7	8,3	9	10	10	10	11
Norway	54	56	58	61	62	68	63	74
Poland	143	145	143	147	156	178	150	212
Portugal	9	9	10	10	16	16	20	20
Romania	72	79	70	78	72	83	69	88
Slovakia	13	13	14	14	18	22	22	34
Slovenia	17	17	18	18	22	25	21	30
Spain	115	115	112	112	111	112	106	110
Sweden	223	247	235	272	251	316	274	396
Switzerland	48	51	68	80	106	147	117	206
United Kingdom	26	30	28	34	32	44	35	57
EU-27 + Norway and Switzerland	**1,721**	**1,833**	**1,842**	**2,034**	**2,098**	**2,505**	**2,085**	**2,888**

Source: BSR-Sustainability 2008



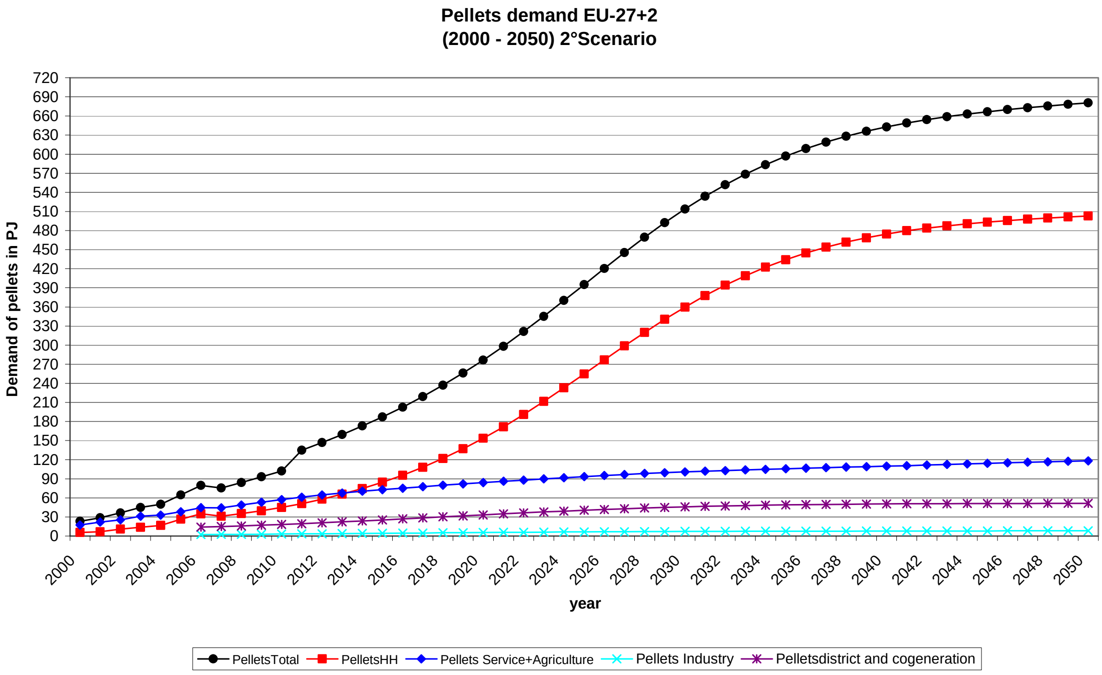
Source: BSR-Sustainability 2008

Figure 5-8: Share of firewood and new forms of fuelwood, 2°C Scenario, 2000 to 2050

The different kinds of fuelwood in detail

As a consequence of policies encouraging energy-efficiency and renewables, and technology improvements, the use of pellets will increase in private households and the service sector and they will also be used in district heating, industry and co-generation (in total almost 690 PJ by the year 2050; see Figure 5-9). It becomes clear that by the year 2050 the use of pellets and wood briquettes occurs with around 503 PJ mainly in private households, but the service sector also has a relevant share (approx. 120 PJ) (see Figure 5-9).

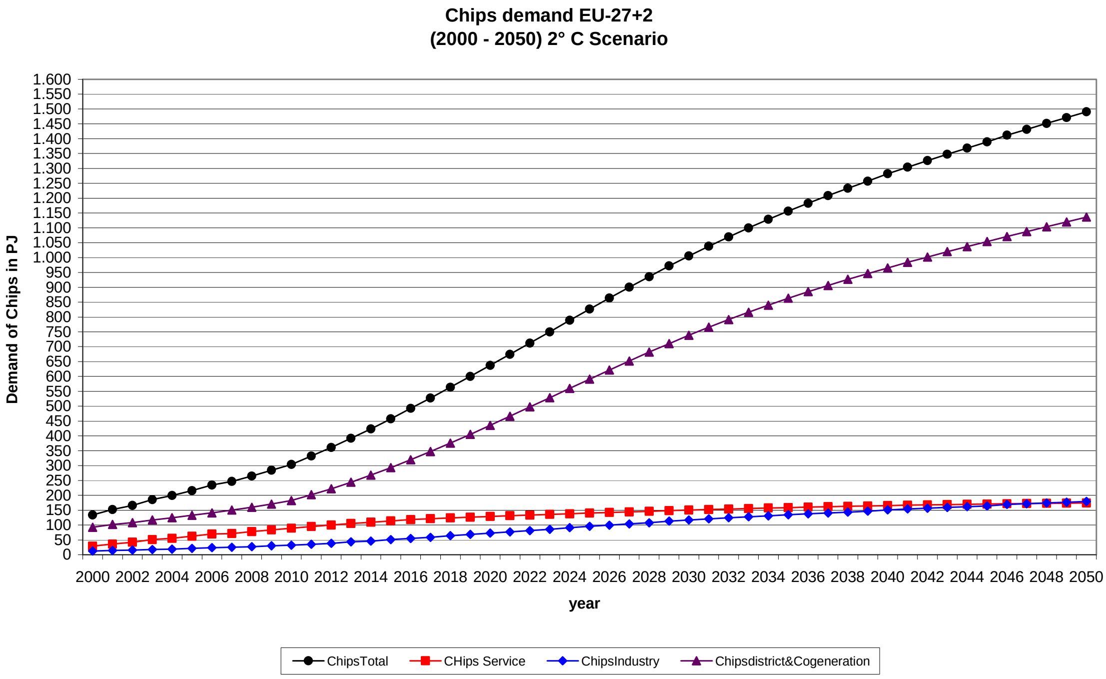
The 2°C Scenario indicates an almost continuous increase in woodchip demand from around 135 PJ in 2000 up to roughly 1,500 PJ in 2050 (+1010%). Woodchips are mainly used in district heating plants, cogeneration and industry (almost 1,320 PJ in 2050). Utilisation of woodchips in the service sector amounts to 140 PJ in 2050 (see Figure 5-10). Woodchip use in the service and agricultural sector is especially frequent in rural areas, which have easily available wood and sufficient storage space for woodchips.



Source: BSR-Sustainability 2008

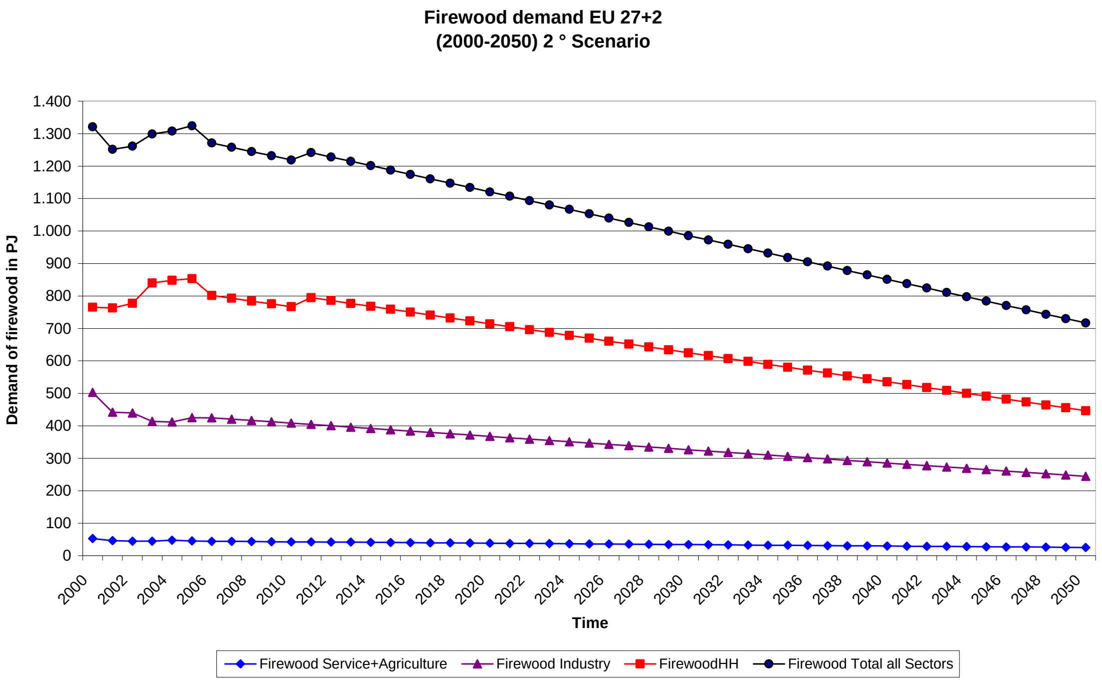
Figure 5-9: Pellet demand (EU27+2) in different sectors, 2°C Scenario, 2000 - 2050

From around 1320°PJ in 2000, firewood decreases to 717°PJ in 2050. In 2050 firewood is mainly used in private households (almost 450 PJ), predominantly in efficient and modern firing plants and no longer in conventional stoves. The majority of firewood is used in the wood gasification plants of family houses (see Figure 5-1).



Source: BSR-Sustainability 2008

Figure 5-10: Chips demand (EU27+2) by sectors, 2° C Scenario, 2000 to 2050



Source: BSR-Sustainability 2008

Figure 5-11: Firewood demand (EU27+2) by sectors, 2°C Scenario, 2000 – 2050

6 Residential sector in Europe

Authors: Eberhard Jochem, Martin Jakob, Giacomo Catenazzi

The residential sector in Europe presently has a share of 26 % in total final energy demand, but a somewhat lower share of direct CO_2 emissions due to the relatively high shares of natural gas use and district heat supply.

The future energy demand of the residential sector has been projected until 2050 using detailed bottom-up models. These are able to explain structural changes and their impact on energy demand more clearly than more aggregated models. Heating, cooking/hot water, and electrical appliances are treated separately as these energy uses depend on different – sometimes diverging – factors such as population and the income of private households. On the other hand, data availability may be poor for some sub-sectors and European countries and the many assumptions which then have to be made to compensate for missing empirical data may offset offset the advantage of higher differentiation. Unique to this report is the inclusion of the building sector's adaptation to climate change in each of the 29 European countries.

6.1 Challenges and objectives of the analysis

The objectives of the analyses and projections in the residential sector were the following:

- (1) The projections up to 2050 should provide a realistic picture of the drivers of energy demand in the residential sector in relation to higher income per capita and household, and the anticipated population development in each country and related ageing.
- (2) The projections should include the impacts of a high adaptation scenario (Reference Scenario) and of an intensive mitigation scenario (called 2°C Scenario) on energy demand as well as on the investments in adaptation or mitigation. The energy demand should be broken down into heating demand, warm water and different electrical appliances.
- (3) Finally, the two scenarios should give a brief outline of the policies that would be needed to achieve the mitigation targets or to adapt to the changing climate in Europe.

The challenges involved in the analysis and projections were determined by the objectives and the available data and models. Multi- and single-family houses should be distinguished and the thermal insulation of the existing building stock should be determined as should the present and evolving efficiencies of several major electrical appliances. Data for Central European countries were often lacking and had to be estimated; the models had to be disaggregated and the influence of changing temperatures on heat demand or air conditioning had to be determined. Finally, investments and cost changes of adaptation and mitigation measures had to be calculated to provide data for the macroeconomic analysis performed using the ASTRA model.

6.2 Methodology and assumptions

The energy demand for heating, warm water and electrical appliances is projected by means of two different models, the RESIDENT model for heating and warm water generation and the RESAPPLIANCE model for all electrical appliances including ventilation and air conditioning. As in the other final energy sectors, two variants of the 2°C Scenario were calculated, one with the emission path of 400 ppm and the other with 450 ppm atmospheric CO_2 concentration by the end of this century.

These two variants of the 2°C Scenario assume the following impacts of mitigation in comparison to the Reference Scenario that does not include any additional climate change policies:

- ambitious mitigation measures through energy efficiency improvements of houses and buildings as well as electrical appliances,
- extensive mitigation measures by substituting fossil fuels with renewable energies (e.g. modern forms of wood, solar thermal, heat pumps), and
- fewer adaptation measures (less cooling demand, but more heating).
- The related macroeconomic changes due to adaptation and mitigation policies (including their programme costs) and due to investments and changing energy costs and other operating costs (see Chapter 13). The macroeconomic impacts (e.g. changes in value added, employment, or trade) are calculated by the ASTRA model.
- There are no changes in the drivers stemming from changing preferences or awareness of the future impacts of climate change, and even slightly changing income per capita in the 2°C Scenario was not considered due to the time limits of the analysis.

As the bottom-up models and the macroeconomic model form a hybrid model system (HMS), interactions between the two types of models are increasingly important with increasing intensity of mitigation policies. However, interactions were not considered due to the project’s time constraints.

The following two sections give a brief description of the two models applied to the residential sector and their major assumptions.

6.2.1 Buildings

The RESIDENT model is a bottom-up simulation model to determine the long-term energy demand for heating and hot water in the residential sector (see also Jochem et al. 2009a). Demand for heat energy is determined as

Energy demand = specific energy demand per floor area **x** *floor area*

Computation is performed sequentially for two types of buildings (single family houses, multi-family houses). The current specific energy demand per floor area is determined by the construction period and the impact of retrofitting. The future specific energy demand for space heating is influenced by the following developments:

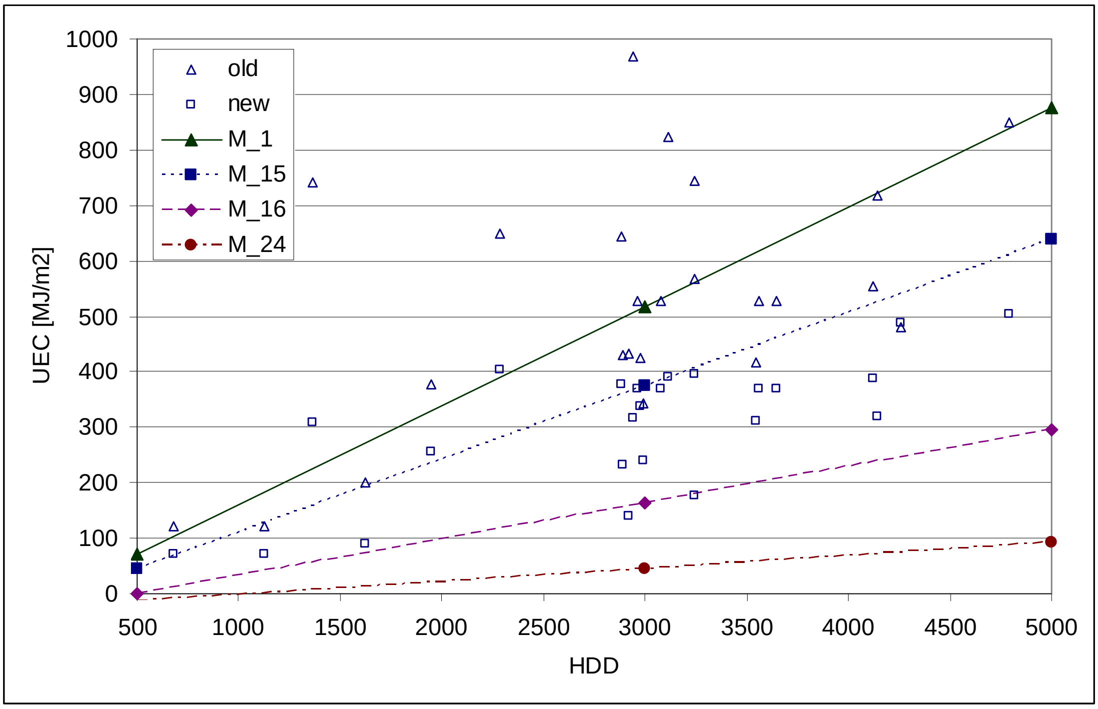
- changes in the building stock over years and decades are captured in a vintage model reflecting the number of buildings newly constructed, renovated or dismantled per year; the average heat demand is calculated for each vintage;
- the average energy efficiency of the heating system is determined by the number of newly installed heating systems in new buildings as well as in existing buildings where old boilers or heating systems are being replaced;
- fuel shares are determined by their shares in new buildings and the estimated interfuel substitution in existing buildings;
- behavioural changes of heating system operators and end-users (e.g. due to energy price changes) are assumed to have the same relative effect on all vintages;
- mitigation policy measures aiming to improve the thermal insulation of buildings and the efficiency of heating, ventilation and air conditioning systems are not explicitly simulated, but are reflected in the technical and behavioural changes mentioned above;
- changing average winter and summer temperatures in the different European countries resulting in changes in how energy is used to in the residential sector: less heating and more cooling compared to present climate in the 4 °C Scenario.

6.2.1.1 Energy efficiency of heating in residential buildings

At present, the strictest building standards are the Minergie-P and Passivhaus standards of Switzerland and Germany, respectively, which greatly reduce the energy demand of buildings. Similar standards and labelling systems are in place in other European countries. For space heating, we were inspired by such standards, and adapted them to the different climates in Europe and different needs.

For both new and old buildings, the specific energy demand of the Minergie-P standard is substantially lower than the current demand of existing buildings and the specific demand of new ones built in line with current practice and regulations (see Figure 6-1). Comparing the present (2004) unit energy demand (UEC) of old buildings (triangles) and new buildings (squares) with the results of a detailed building simulation model, the authors defined four classes of buildings (and related energy demand): buildings without energy saving measures

(M_1), typical European new buildings (M_15), strict building standards (Minergie, M_16), and Minergie-P (or passive houses; M_24). These figures are displayed for EU27+2 according to the different climates (measured in yearly heating degree days, HDD; see Figure 6-1).



Source: CEPE's assumptions

Figure 6-1: Specific energy demand for heating (in MJ/m²) in multi-family houses for existing buildings (old: old buildings, new: buildings of 2004), and for simulated buildings (M_1: without special energy efficiency measures; M_15: typical new buildings in 2004; M_16: energy efficiency similar to Minergie; M_24: energy efficiency similar to Minergie P/ Passivhaus) as function to heating degree days

Based on these data and the building simulation model (IDA-ICE), the authors defined an ambitious efficiency improvement to the building codes for new buildings: an improvement of 56 % between 2010 and 2016 and of 72 % to 2025 for the 450 ppm variant. Starting from 2026, a yearly technical progress of 0.25 % is assumed (0.2 % in the Reference scenario). The figure of the first period represents a Minergie standard (38 kWh per m^2 including warm water), and that of the second period indicates a building code between Minergie and MinergieP (15 kWh/m^2; or alternatively that 50 % of buildings will be built as MinergieP and the other half as Minergie). Using a single relative improvement for all countries forces the Nordic countries to adapt a more advanced insulation level and indoor air exchange control.

Stricter policies are assumed in the 400 ppm variant of the 2°C Scenario, which result in an 88 % reduction in heat demand relative to the present energy demand of the building stock. This means that all new buildings (on average) are expected to fulfil the Minergie-P standard by 2025.

A similar assumption is made with regard to retrofitting buildings: retrofitted buildings are expected to have a unit energy demand which is around 10% higher than new buildings, starting from 2016. The yearly retrofit rate, that is the share of buildings to be retrofitted relative to the building stock, increases from 0.8 % (in 2020) and 0.5 % (in 2050) in the Reference Scenario to 1.8 % and 1.3%, respectively, in the 450 ppm variant of the 2°C Scenario and to 1.8 % and 2.1 %, respectively, in the 400 ppm variant. This implies an enormous speed up in the retrofitting activities in residential houses and buildings with the result that 75 % of old buildings (before 1950) and 84 % of the intermediate cohort of the buildings contructed between 1950 and 1980 are retrofitted in the 450 ppm variant by 2050 and 86 % to 93 %, respectively, in the 400 ppm variant.

These assumptions regarding the accelerated yearly retrofit rate are extremely ambitious. However, they still assume that energy-relevant retrofittings are less effective and more costly than improvements to new buildings and that some technical obstacles reduce the effectiveness of improvements (facades in old town centres, higher room height, unavoidable heat bridges, etc.).

The energy demand for hot water generation and the additional electricity demand for the ventilation systems required by highly insulated houses and buildings are described in Section 6.2.2.1.

6.2.1.2 Substitution of fossil fuels

As residential sector floor area is increasing in all European countries, even the high thermal insulation assumptions will not be sufficient to reduce the CO_2 emissions of this sector. Therefore, additional assumptions about the substitution of fossil fuels had to be made.

As the shares of fossil fuels in total final energy demand vary among the European countries, a general rule for the declining use of fossil fuels was assumed and applied equally to all European countries over the projection period (see Table 6-1). In the 450 ppm variant of the 2°C Scenario, for instance, the coal share for heating was set at zero in 2050 and the share of heating oil was reduced to 35 % of its 2005 value (see Table 6-1). Natural gas and electricity only decrease to 80 % of their 2005 value until 2050 in the 450 ppm variant. However, they decline strongly in 400 ppm variant. Similar patterns were assumed for propane and "others".

The absolute energy figures for wood and pellets are set at nearly the maximum supply potential of Europe, with some inter-European trade and low imports from Russia and Canada. Heat pumps also gain substantial market shares until 2050 in absolute terms. The biogas demand is implicitly included in the demand for natural gas. Because of its relatively restricted availability and a potentially high demand, buildings, transportation and the conversion sector are in competition for biogas (and biomass in general). For this reason, the split of biogas use among the different sectors is determined in the renewables chapter (see Chapter 10).

Table 6-1: Changes in the fuel shares of heating energies of residential buildings in Europe in the two variants of the 2°C Scenario, 2005 to 2050

	450 ppm variant			400 ppm variant	
	2010	**2030**	**2050**	**2030**	**2050**
Coal	90%	40%	0%	30%	0%
Heating oil	95%	65%	35%	52%	21%
District heat	100%	85%	65%	77%	52%
Firewood	is given in absolute energy terms			absolute energy terms	
Natural gas	99%	90%	80%	63%	24%
Electricity	98%	90%	80%	54%	16%
Heat pumps (el.)	is given in absolute energy terms			absolute energy terms	
Propane	100%	100%	100%	60%	40%
Pellets	is given in absolute energy terms			absolute energy terms	
Solar	102%	110%	133%	132%	186%
Biogas	is given in absolute energy terms			absolute energy terms	
Others	100%	100%	100%	60%	40%

Source: CEPE's assumptions

6.2.1.3 Impact of adaptation

In the first stage, the specific energy demand for lighting, ventilation, cooling, appliances, heating and other thermal applications is modelled for different building types and locations in Europe. 14 locations are chosen to cover the relevant regions both in terms of the energy demand of the residential and tertiary sector and the range of climate conditions in Europe.

Energy demands (and indoor climate conditions) are estimated with a dynamic building simulation model (IDA-ICE). Simulation results differentiate between the main types of energy services, namely lighting, ventilation, cooling, heating and other thermal applications, and will reveal the impact of climate change on the specific energy demand and the need for adaptation measures in buildings to ensure an acceptable level of comfort for their occupants. The impact estimated by our own building model simulation is backed up by evidence from the literature, particularly from Rivière, Adnot et al. (2008), Cartalsi, Synodinou et al. (2001), Frank (2005) and Aebischer et al. (2007). A longer description is given in the second deliverable of this work package, in Jochem *et al.* (2009b).

Regarding the efficiency of cooling appliances, we assume an improvement of about 65 % over the next 45 years in the 450 ppm variant of the 2°C Scenario. This is technically feasible (Adnot 2003; Adnot, 2008) due to the use of better technologies, cooling fluids and the removal of inefficient systems from the market, thus using more split air conditioning by regulation.

Moving towards the "Passivhaus" standard requires controlled ventilation and such buildings are often equipped with heat pumps to generate the remaining heat demand. Ventilation systems will aid the efficient cooling of buildings by providing free or overnight cooling and thus avoid the need for less energy-efficient room air conditioning. In general, modern ventilation systems will reduce the felt temperature by one to two degrees centigrade.

In the 400 ppm variant, we assume that further efficiency improvements are possible. However these improvements are compensated by the additional electricity demand for the increased use of ventilation (in winter and in summer).

6.2.1.4 Cost of mitigation and adaptation

In many instances when investments in improved energy efficiency have to be monetarised, there are no concrete data on the additional investment costs that can be attributed to the improved efficiency. There are various reasons for the lack of data: in some cases involving, e.g. electrical appliances or cars, the pricing policy of the manufacturer dominates the price difference between a less and a more efficient product; in other cases, the new, more efficient products may also have additional functions (e.g. more selection options for washing or drying, greater comfort in new cars) so that the specific effect of improved efficiency cannot be identified in the price changes. However, it is quite clear from a technical point of view that the more efficient solution is profitable. In yet other cases, like the many thermal insulation investment options, it would be extremely cumbersome to survey the additional investments attributable to additional efficiency performance in all the possible building types and sizes. Indeed, in this last case it would be impossible to identify the net cost and energy savings of the many thousands of different combinations of investments.

This is why Jochem and Bradke (1996) developed a very simple method in order to estimate the investment costs of additional energy efficiency. The method uses a simple economic rule: "*People are inclined to invest additional money if they expect that they will save more money over the lifespan of the new investment*'", i.e. if the investment can be considered to be profitable.

The investment costs for thermal insulation in single family houses are around 100 to 5,000 € per annually saved MJ in the 450 ppm variant and about 200 to 6,000 € in the 400 ppm variant. The huge difference in investment is due to the initial level of insulation, the reduced energy demand, and the fuel prices determining the reduced energy cost. The payback time is estimated to be 25 years.

For re-investments in heat generating systems, the interval of investment was chosen to be between 15 and 30 years, also depending on the new fuel in case of fuel substitution. The investment costs vary between energy systems and the size of buildings (see Table 6-2).

Table 6-2: Investment cost (in Euro per square metre) of a replaced heating system for hot water generation and for different types of buildings

	hot water	single family house	multi family building	service sector
Electricity	11.9	55.4	22.7	16.3
Electric heat pump	32.2	138.8	68.4	53.8
District heat	13.1	60.2	25.2	18.1
Oil boiler	23.0	112.5	40.0	28.6
Gas boiler	20.3	99.4	35.3	25.3
Wood, pellets boiler	25.9	127.5	44.7	32.0
Solar thermal collector	30.4	124.9	68.8	51.8
Others	23.0	112.5	40.0	28.6

Source: P. Hofstetter and M. Jakob (2006), M. Jakob, 2003, and CEPE's assumptions

Regarding heating, there are no (direct) adaptation costs in terms of investments due to a warmer climate. The model does not assume reduced investments as the capacity of boilers and heating systems have to serve maximum heat demand in very cold periods in winter seasons. Regarding operating cost, the residential sector stands to gain somewhat due to slightly reduced energy costs for heating.

Adnot (2007) estimated the investment costs of air conditioning for several European countries: the values are in the range between 335 € and 695 € per movable air conditioner, and between 450 € and 1,215 € for split air conditioners. This means investment cost between 130 € and 240 € per installed thermal kW. To calculate the investment costs of additional air conditioning, a re-investment cycle of 15 years is assumed. Only one third of the invested air conditioners is included in the additional investment costs due to adaptation: nearly 2/3 of the air conditioner investments will be made in any case due to higher per capita income and increasing demand for comfort according to the assumptions in the Base Case Scenario.

6.2.2 Energy efficiency of non-heating uses and of electrical appliances

The future energy demand of non-heating uses and various electrical appliances reflects the different intensity of mitigation policies (see Table 6-3). The assumptions for improved efficiencies are not differentiated among the European countries as the trade of electrical appliances in Europe is very high and the European labelling schemes support this homogenous technical performance of ecletrical appliances. This also explains little dfferences between the assumptions in the EU15+2 countries and the New Member States (NMS, see Table 6-3).

Table 6-3: Yearly efficiency improvement for non heating uses and electrical appliances EU15 +2 and New Member States, Reference and 2°C Scenario, 2020 to 2050

	EU15+2			New Member States		
	Reference	**450ppm**	**400ppm**	**Reference**	**450ppm**	**400ppm**
Hot water	-0.8%	-1.0%	-1.3%	-0.6%	-1.0%	-1.3%
Cooking	-0.7%	-1.2%	-1.5%	-0.7%	-1.3%	-1.5%
Lighting	-1.0%	-5.3%	-5.5%	-1.0%	-6.0%	-5.5%
Refrigerators	-0.7%	-2.9%	-3.2%	-0.5%	-1.5%	-3.2%
Freezers	-0.8%	-3.8%	-4.1%	-0.6%	-3.8%	-4.1%
Washing machines	-0.8%	-4.8%	-5.0%	-0.8%	-4.3%	-5.0%
Dishwashers	-0.8%	-3.0%	-3.3%	-0.8%	-3.0%	-3.3%
TV	-0.5%	-2.5%	-2.9%	0.0%	0.0%	-2.9%
Others	2.2%	1.5%	1.0%	7.6%	5.7%	4.5%
AC	-0.5%	-3.0%	-3.0%	-0.5%	-3.0%	-3.0%

Source: CEPE's assumptions

6.2.2.1 Hot water, cooking and lighting

With regard to the three energy services - hot water, cooking and lighting – the authors assumed the development of specific energy demand by the foloowing considerations:

- Specific energy demand for hot water is diminuished from 0.6 %-0.8 % per year in the Reference Scenario to 1.0 % per year in the 450 ppm variant and to 1.3 % per year in the 400 ppm variant of the 2°C Scenario. The relative small gain is due to the improvement of heat losses by better insulation and control and some improvement of boiler efficiencies. However, most of the energy use is useful energy, which cannot be reduced without reducing the use of hot water, which was excluded by scenario definition.
- Specific energy demand for cooking could be further decreased by using ceramic cooking or induction cooking increasing efficiency from 0.7 % per year to 1.2 % - 1.3 % per year (450 ppm variant) or to 1.5 % per year (400 ppm variant); such substitutions have long market penetration periods as preferences and traditions play an important role.
- Lighting has large efficiency potentials in the residential sector, using high efficient illumination options (including diode lighting (LED) in the near future). Due to very short

re-investment cycles of incandescent lighting, the improvement could be very fast. The authors estimate savings of some 85 % (450 ppm variant) to 87 % (400 ppm variant) per dwelling at the middle of this century. The new member states have some more potential, because they start from a higher market share of traditional bulbs.

6.2.2.2 Electrical appliances

The future efficiency improvement in white good can be substantial as demonstrated by the top ten appliances that are actually on the market[1]. These data (from topten.ch) were used as the target and average specific electricity demand for 2040 (450 ppm variant) or for 2030/2035 (400 ppm variant; see Table 6-4). The authors assume that this trend of efficiency improvement continues until 2050. The differences between EU15+2 and the New Member States (NMS) are due to the different present levels of electiricty demand: in the NMS, the technical improvement is partially set off by larger appliances and by faster market diffusion.

Table 6-4: Yearly electricity demand of selected appliances (in MJ per year) of the present stock, standard new appliances and currently most efficient (top-ten) appliances, and relative improvement replacing old appliances by standard and top ten appliances, Europe, 2005

	Specific electricity demand (MJ/a)			Improvement in percent	
	present stock	new appliances	Top Ten	Difference new / stock	Difference Top Ten / stock
Refrigerator	1865	1140	614	-39%	-67%
Freezer	1762	1078	583	-39%	-67%
Kitchen stove	1078	936	720	-13%	-33%
Dishwasher	1486	1128	566	-24%	-62%
Washing machine	828	684	204	-17%	-75%
Tumble dryer	2071	1843	922	-11%	-56%

Source: http://topten.ch (EnergieSchweiz, SAFE)

Specific electricity demand of television sets and similar electrical appliances (video recorders, set-top boxes etc.) as welll as of information and communication appliances have been estimated by the autors on the basis of existing literature. Regarding televisionsets, the LCD screen will contribute to reduce the electricity demand (but only little due to larger screens). In many other cases, larger appliances and/or stand-by demand and accessories (e.g.

1 Top-ten is an information and dissemination platform that collects information of the most efficient appliances of each type. It exists in the following countries: Austria, Belgium, Czech Republic, Finland, France, Germany, Italy, Luxemburg, Netherlands, Poland, Portugal, Spain, Switzerland (see http://topten.info)

set-top-boxes) will contribute to increasing electricity demand of private households in the future.

6.2.2.3 Cost of mitigation and adaptation

Regarding the costs of mitigation of non-heating uses, we use the method of "applicable investment cost" (see the building section 6.2.1.4 and Jochem and Bradke, 1996). The specific investment costs increase by some 20 % for each category of appliance with increasing efficiency between 2010 and 2050 (see Table 6-5). Improving the efficiency of cooking implies a threefold higher investment per yearly saved MJ as compared to investments in high efficient heating systems.

Table 6-5: Assumed payback time to calculate applicable investment cost for energy-efficient electrical appliances and investments (in € per saved MJ per year); Europe, 2010 to 2050

	pay-back time in years	2010	2020	2035	2050
White electrical appliances	8	0.4	0.4	0.5	0.5
lighting	8	0.4	0.4	0.5	0.5
entertainment & communication	12	0.6	0.7	0.7	0.7
heating systems	20	0.3	0.4	0.5	0.5
hot water	20	0.3	0.4	0.5	0.5
cooking	20	1.0	1.1	1.2	1.2

Source: CEPE's assumptions

Of course, all these assumptions on technical and cost data could be discussed and sensitivity calulations with changed assumptions could be applied to identify those areas where results achieved are sensible to the assumptions made here. Due to time constraints sensitivity analyses were not undertaken.

6.3 Results of the Reference and of the variants of the 2°C Scenario

The results of the heating energy demand and the electricity demand of electrical appliances are discussed in separate sections. The results of the Reference Scenario have been presented and commented in more detail ind the foregoing deliverable (D.2 of the work package; see Jochem et al. 2009 b).

6.3.1 Energy savings in residential sector

For Europe as a whole, the final energy demand for space heating will decrease continuously throughout the period in both scenarios. In the Reference Scenario, the impact of the warmer climate (+4°C at the end of this century) amounts to a decrease in space heating by some 1,400 PJ or -16 % for EU27+2 in 2050 (see section 6.2.2.1 in Jochem et al. 2009). The changes vary in the different European countries.

The heating demand decline in buildings in the Nordic and Baltic countries is small in relative terms (changes of 13 to 15 %), but large in absolute terms. In contrast, the decrease in Mediterranean countries by the year 2050 is large in relative terms (16 to 33 %) but comparatively small in absolute energy terms relative to a Base Case Scenario. The reductions here are higher in relative terms due to the larger changes in heating degree days (HDD). However, specific heating demand in absolute terms is currently much higher in the Nordic countries, so in absolute terms, the reduction in energy demand (and the economic benefits associated with this) is much higher in countries north of the Alps.

In the 2°C Scenario, total final energy demand is reduced by slightly more than half in the 450 ppm variant and by about two thirds in the 400 ppm variant as compared to the Reference Scenario (Table 6-6). The reductions are quite similar in all European regions due to the same technological improvements and related polices (such as the building directive, the eco design directive, harmonising labelling schemes and regulation). As compared to the 2005 level of final energy demand, the reduction is 58 % and 69 % in the 450 ppm variant and the 400 ppm variant respectively. The slightly higher heat demand in the 2°C Scenario due to a lower climate change relative to the Reference Scenario has been taken into account.

Table 6-6: Final Energy demand for space heating in the residential sector in PJ, European regions, Reference and 2°C Scenario, 2005 to 2050

Region	Reference Scenario				450 ppm variant				400 ppm variant			
	2005	2020	2035	2050	2035	2020	2050	diff[1)]	2035	2020	2050	diff[1)]
North	515	470	474	444	415	294	215	-52%	414	270	161	-64%
South	1618	1529	1506	1337	1367	962	652	-51%	1364	896	489	-63%
East	1107	1079	1012	926	949	654	430	-53%	947	597	303	-67%
West	5343	5042	5148	4758	4407	3155	2300	-52%	4390	2900	1729	-64%
EU27(9)	8584	8121	8140	7465	7138	5065	3598	-52%	7115	4663	2682	-64%

[1)] compared to the Reference Scenario in 2050

Source: CEPE's results

In the Reference Scenario, electricity demand increases by 1,100 PJ or more than 60 % between 2005 and 2050 (see Table 6-7). The relative large increase of electricity demand by electrical appliances (+95 %) in East European countries is caused by relatively intensive diffusion of appliances, starting from currently still quite low diffusion levels (e.g. dishwashers, freezers, TV-sets) and an increasing number of dwellings (due to decreasing occupancy density). Hence, the basic observation is that the shift towards more efficient electrical appliances does not compensate the additional electricity demand due to further market penetration of the various and new electrical appliances in the Reference Scenario (see also section 6.3.2.1 in Jochem et al 2009 b).

The results of the two variants of the 2°C Scenario demonstrate the large efficiency potentials of electrical appliances (see Table 6-7): The electricity demand slightly increases until 2020, before it stagnates at present levels at around 1,760 PJ between 2035 and 2050 in the 450 ppm variant. This means that the increasing energy services of this sector can be completely offset by the additional efficieny gains during the coming decades. In the 400 ppm variant, present electricity demand can even be reduced by a further 14% until 2050 (see Table 6-7) or by almost 50 % compared to the demand in the Reference Scenario in 2050.

Table 6-7: Electricity demand for electric appliances, European regions and EU27+2, Reference and 2°C Scenario, 2005 to 2050

El. appliances	Reference Scenario				450 ppm variant				400 ppm variant			
	2005	2020	2035	2050	2035	2020	2050	diff[1)]	2035	2020	2050	diff[1)]
North	143	160	178	194	141	127	121	-38%	135	115	106	-46%
South	500	634	757	858	548	516	507	-41%	527	465	434	-49%
East	153	192	239	298	165	164	186	-38%	159	147	151	-49%
West	968	1157	1353	1514	1007	954	941	-38%	968	865	819	-46%
EU27(9)	1764	2144	2528	2864	1861	1762	1755	-39%	1789	1593	1509	-47%

1) Compared to the Reference Scenario in 2050

Source: CEPE's results

The demand for air conditioning in Europe is greatly increasing from 23 PJ in 2005 to some 116 PJ until 2050 in Reference Scenario which is still a small share of 4 % in 2050 (see Table 6-8). In absolute terms, the major impacts are in the southern countries, because of the larger air cooled area and high yearly operating hours. In these countries the saturation level of air conditioners is almost reached in 2050. In relative terms, the areas most affected are West and East Europe, because of the lower initial level, but with greater need for additional cooling (compared to the northern countries).

Table 6-8: Electric demand for cooling and ventilation, European regions, Reference and 2°C Scenario, 2005 to 2050

Region	Reference Scenario				450 ppm variant				400 ppm variant			
	2005	2020	2035	2050	2035	2020	2050	diff[1)]	2035	2020	2050	diff[1)]
North	0.2	1.0	1.4	1.5	0.9	0.9	0.6	-58%	0.9	0.9	0.6	-58%
South	20.6	62.2	86.5	94.2	53.8	51.9	42.2	-55%	53.8	51.9	42.2	-55%
East	0.6	1.6	2.7	3.2	1.4	1.5	1.3	-60%	1.4	1.5	1.3	-60%
West	2.0	8.0	14.1	16.9	6.9	8.0	6.7	-60%	6.9	8.0	6.7	-60%
EU27(9)	23	73	105	116	62.9	62.3	50.8	-56%	62.9	62.3	50.8	-56%

[1)] compared to the Reference Scenario in 2050

Source: CEPE's results

In both variants of the 2°C Scenario, the demand for more cooling services can be partly compensated by more efficient cooling appliances and building concepts. Electricity demand in 2050 for cooling only increases to the level of about 2017 of the Reference Scenario which is also due to the fact that cooling degree days will be lower in the 2°C Scenario in comparison to the Reference Scenario.

The following tables show the summarised results of the two sectors on heating and electrical appliances, including cooking with gas or hot water generation by electricity. While the fuel demand is sightly reduced from 9,856 PJ in 2005 to around 8,200 PJ in 2050 in the Reference Scenario (-17 %) (see Table 6-9), the decline is substantial in the two variants of the 2°C

Scenario reaching 4,120 PJ (-57 % relative to 2005) in 2050 and about 2,200 PJ (-78 % relative to 2005) respectively in the 400 ppm variant. The countries with cold and warm climates reduce their fuel demand slightly less than the West and East European countries (see Table 6-9).

The electricity demand of the residential sector increases by 30 % between 2005 and 2050 in the Reference Scenario, being dominated by the increase of the electrical appliances (see above). While electricity demand of North Europe is stagnating over the whole period (due to decreasing electricity demand for heating which offsets the increase of the electrical appliances), the electricity demand of South Europe increases by 50 % due to increasing air conditioning and the growing stock of electrical appliances (see Table 6-9). The improvements of the electrical uses in private households in the 2°C Scenario relative to the Reference Scenario are somewhat less pronounced than in the fuels demand: their growth in energy efficiency is 36 % at the EU27+2 level in 2050 in the 450 ppm variant and 42 % in the 400 ppm variant respectively. Again this reflects the relative high share of heating in electricity use in the Scandinavian countries where heat demand can more easily be reduced as the electricity demand of electrical appliances.

Table 6-9: Fuels demand in the residential sector, European countries and EU27+2, Reference Scenario and 2°C Scenario, 2005 to 2050

Fuels	Reference Scenario				450 ppm variant				400 ppm variant			
	2005	2020	2035	2050	2035	2020	2050	diff[1)]	2035	2020	2050	diff[1)]
Austria	228	211	201	174	197	144	106	-39%	182	124	81	-54%
Baltic States	144	129	113	97	117	78	49	-50%	113	66	31	-68%
Belgium/Lux.	379	347	348	312	294	191	127	-59%	257	128	61	-80%
Bulgaria	59	53	46	40	48	32	19	-51%	46	27	13	-68%
Czech Republic	194	181	167	151	163	116	80	-47%	149	86	45	-70%
Denmark	141	126	122	110	110	75	53	-52%	98	54	30	-73%
Finland	134	114	100	86	107	76	55	-36%	100	70	48	-44%
France	1247	1253	1253	1148	1021	744	570	-50%	899	530	306	-73%
Germany	2207	2011	1968	1726	1746	1193	820	-52%	1557	860	415	-76%
Greece	158	139	139	132	118	79	56	-58%	105	60	38	-72%
Hungary	203	185	166	147	161	107	69	-53%	144	74	35	-76%
Ireland	84	94	104	103	80	60	44	-57%	73	43	23	-77%
Italy	940	874	855	742	775	553	390	-47%	678	367	180	-76%
Malta/Cyprus	10	11	12	11	9	7	5	-50%	8	5	4	-64%
Netherlands	351	317	300	263	280	196	137	-48%	239	124	57	-78%
Norway	42	41	45	43	41	43	41	-4%	42	43	37	-13%
Poland	639	631	594	542	536	361	241	-55%	497	282	149	-73%
Portugal	82	77	70	57	68	44	28	-50%	63	42	28	-52%
Romania	282	268	248	222	240	165	105	-53%	220	121	55	-75%
Slovakia	96	90	83	76	76	48	31	-59%	69	36	17	-77%
Slovenia	35	38	38	36	33	24	17	-52%	32	20	11	-68%
Spain	480	473	455	403	438	343	263	-35%	411	286	191	-53%
Sweden	162	153	148	137	149	114	92	-33%	134	99	76	-44%
Switzerland	165	149	144	118	128	88	60	-49%	114	65	39	-67%
United Kingdom	1394	1295	1343	1323	1126	841	662	-50%	947	489	215	-84%
EU27+2	9856	9258	9061	8198	8064	5721	4123	-50%	7179	4101	2184	-73%
North	480	433	415	375	407	308	241	-36%	374	265	191	-49%
South	2011	1895	1825	1608	1697	1222	868	-46%	1532	908	508	-68%
East	1311	1254	1161	1049	1086	734	487	-54%	1004	565	289	-72%
West	6054	5676	5660	5167	4874	3457	2527	-51%	4269	2363	1197	-77%
EU27+2	9856	9258	9061	8198	8064	5721	4123	-50%	7179	4101	2184	-73%

[1)] compared to the Reference Scenario in 2050

Source: CEPE's results

Table 6-10: Electricity demand in the residential sector, European countries and EU27+2, Reference Scenario and 2°C Scenario, 2005 to 2050

Electricity	Reference Scenario				450 ppm variant				400 ppm variant			
	2005	2020	2035	2050	2035	2020	2050	diff[1)]	2035	2020	2050	diff[1)]
Austria	47	52	60	64	42	37	33	-49%	47	39	32	-51%
Baltic States	22	27	31	36	23	21	22	-39%	23	21	19	-47%
Belgium/Lux.	57	64	71	77	60	58	55	-28%	71	69	58	-25%
Bulgaria	30	34	37	39	30	26	24	-40%	29	22	19	-52%
Czech Republic	54	60	59	61	53	42	38	-39%	51	37	29	-52%
Denmark	39	41	44	46	34	30	28	-40%	38	34	30	-35%
Finland	73	77	83	82	65	55	48	-42%	65	48	35	-57%
France	518	541	599	631	481	437	404	-36%	488	399	332	-47%
Germany	465	473	497	513	437	400	375	-27%	478	419	356	-31%
Greece	79	88	89	94	76	59	52	-44%	79	60	48	-49%
Hungary	46	48	51	56	44	39	39	-32%	46	38	32	-43%
Ireland	19	29	37	45	27	29	30	-33%	28	31	30	-33%
Italy	243	296	336	357	264	241	222	-38%	285	259	220	-38%
Malta/Cyprus	8	11	13	15	9	9	9	-39%	9	8	7	-52%
Netherlands	71	83	96	105	73	70	70	-33%	85	81	72	-31%
Norway	106	106	110	116	92	67	56	-52%	82	48	34	-71%
Poland	105	120	141	169	110	110	118	-30%	119	113	101	-40%
Portugal	51	61	72	80	57	61	61	-24%	55	49	45	-44%
Romania	44	64	85	106	57	62	68	-36%	60	61	57	-46%
Slovakia	19	21	24	27	20	21	21	-25%	20	18	15	-44%
Slovenia	9	10	11	13	9	9	9	-32%	9	8	7	-45%
Spain	244	294	341	369	258	240	225	-39%	253	219	191	-48%
Sweden	149	122	123	124	98	79	68	-45%	103	74	56	-55%
Switzerland	55	59	63	59	52	45	38	-37%	56	46	33	-44%
United Kingdom	404	475	536	584	426	391	369	-37%	458	418	372	-36%
EU27+2	2957	3255	3607	3868	2898	2637	2478	-36%	3038	2618	2230	-42%
North	366	346	360	368	289	231	200	-46%	289	204	155	-58%
South	699	848	972	1059	753	698	660	-38%	769	679	587	-45%
East	255	286	317	362	258	241	246	-32%	268	235	204	-44%
West	1637	1775	1958	2079	1598	1467	1373	-34%	1712	1501	1284	-38%
EU27+2	2957	3255	3607	3868	2898	2637	2478	-36%	3038	2618	2230	-42%

1) compared to the Reference Scenario in 2050

Source: CEPE's results

It was clear from the very beginning of the analysis that in addition to more energy-efficient solutions there would be also fossil fuel substitution necessary in order to reach ambitious greenhouse gas reduction targets. The reduction of heating oil by more than 50 % in the Reference Scenario is topped by additional 67 % in 2050 in the 450 ppm variant and additional 81 % in the 400 ppm variant. Natural gas has a somewhat better looser perspective as its use stagnates in the Reference Scenario and only reduces at a similar rate its demand in the 400 ppm variant by 88 % (see Table 6-11). Most interesting is that also district heating looses enormous market shares particularly in the 400 ppm variant of the 2°C Scenario. The relative and absolute winners are the renewables (heat pumps, woodfuel, and thermal solar collectors): starting from some 940 PJ in 2005 they reach around 1,179 PJ in 2050 in the Reference Scenario and 1,750 PJ in the 400 ppm variant.

Table 6-11: Fuels demand by different energy carriers in the residential sector in PJ, EU27 + 2, Reference Scenario and 2°C Scenario, 2005 to 2050

	Reference Scenario				450 ppm variant				400 ppm variant			
	2005	2020	2035	2050	2020	2035	2050	diff[1)]	2020	2035	2050	diff[1)]
Electricity (with out heat pumps)	2947	3220	3549	3796	2838	2507	2331	-39%	2619	2066	1771	-53%
Heat pumps	10	35	58	73	146	188	172	136%	419	552	459	532%
Heating oil	2084	1470	1237	990	1123	475	186	-81%	1005	333	86	-91%
Natural gas	5073	5325	5361	5007	4574	3228	2277	-55%	3858	1803	576	-88%
Wood, pellets	905	835	980	928	867	1023	964	4%	876	993	805	-13%
Thermal solar	28	93	141	165	117	199	262	59%	255	423	488	196%
District heating	1012	984	901	752	840	478	246	-67%	789	378	144	-81%

1) compared to the Reference Scenario in 2050

Source: CEPE's results

The diversification of fuels in the residential sector projected for the year 2050 in the 400 ppm variant is quite obvious looking at the total of the EU27+2 (see Table 6-11) or at the national level (see Figure 6-2). Heating oil and gas have small shares in all countries while woodfuel in form of chips and pellets have dominating roles in countries with larger forests areas (see the Baltic States, the Scaninavian countries, Austria, Switzerland, Romania or Bulgaria). Solar thermal collector systems are widely used in the mediterranian countries as one would expect given the favourable conditions in those European contries (see Figure 6-2).

To conclude: the structure of final energy of the residential sector will undergo substantial changes away from fossil fuels to renewable energies (including heat pumps) and, herewith contribute a lot to reduced CO_2 emissions of the European countries assuming an ambitious climate change policy that start early in the coming years.

Policies that are suited to reach these efficiency improvements and mitigsation results are shortly mentioned in section 6.5.

Figure 6-2: **Shares in final energy of the residential sector, EU27+2 countries, 400 ppm variant of the 2°C Scenario, 2050**

6.3.2 Changes of cost and investments

While the foregoing sections looked into the impacts of adaptation and mitigation from a technical point of view, this section focuses on the direct economic impacts in the residential sector regarding changed energy cost and additional investments due to adaptation and mitigation in the two scenarios. Total energy cost of the European residential sector will increase from some 190 Bill. € in 2005 to more than 250 Bill. € in 2050 in the Reference Scenario driven by increasing electricity demand (see Table 6-12). In contrast to this development, the energy cost will decrease in both variants of the 2°C Scenario (-12 % in the 450 ppm variant and -45 % relative to 2005 in the 400 ppm variant). Relative to the Reference Scenario in 2050, the decline is 33 % and 58 % respectively. However, these savings are needed to finance enormous capital cost of the investments of the mitigation scenario.

Table 6-12: Fuels and electricity costs of the residential sector, in billion EUR, Reference Scenario, European region and EU27-2, 2005 to 2050

Region	Reference Scenario				450 ppm variant				400 ppm variant			
	2005	2020	2035	2050	2020	2035	2050	diff[1)]	2020	2035	2050	diff[1)]
North	18	18	19	19	14	12	13	-32%	13	10	9	-52%
South	44	51	55	56	39	38	35	-37%	36	29	23	-59%
East	14	16	17	20	19	14	14	-27%	18	11	9	-53%
West	115	134	150	157	126	109	105	-33%	119	84	63	-60%
EU27+2	191	219	242	252	198	173	168	-33%	187	135	105	-58%

[1)] compared to the Reference Scenario in 2050

Source: CEPE's results

The investments for adaptation of the residential sector are quite small. In total, they reach half a billion € in 2050 with high increases in air conditioning investments in South and East Europe (see Table 6-13). These investment are cut in half in the two variants of the 2°C Scenario and of minor importance relative to the investments for mitigation in the two variants of the 2°C Scenario (see Table 6-14).

Table 6-13: Yearly investment for adaptation in billion €/a, residential sector, Reference and 2°C Scenario, European regions and EU27+2, 2020-2050

Region	Reference Scenario (4°C)				2°C Scenario			
	2020	2020	2035	2050	2020	2035	2050	diff[1)]
North	0.01	0.03	0.06	0.07	0.03	0.04	0.03	-56%
South	0.00	0.02	0.03	0.04	0.02	0.02	0.02	-54%
East	0.02	0.10	0.13	0.17	0.08	0.08	0.07	-60%
West	0.07	0.18	0.22	0.24	0.14	0.13	0.10	-56%
EU27+2	0.10	0.33	0.44	0.52	0.27	0.26	0.22	-57%

[1)] compared to the Reference Scenario in 2050

Source: CEPE's results

The yearly investments in mitigation have been split into investments due to efficiency investments and to fuel substitution. The yearly investments for mitigation peak during the 2030s at some 85 bill. € in the 450 ppm variant and slightly above 100 bill. € in the 400 ppm variant (see Table 6-14). This peaking may be underestimated as some re-investments in boilers, ventilation systems or windows in the 2040s may not have been fully considered by the authors in the model calculations.

The additional investments due to fuel substitution are about 10 % of the investments for mitigation in the 400 ppm variant and less than 3 % of the investments in the 450 ppm variant (see Table 6-15). The fivefold increase of substitution investments clearly shows that the additional CO_2 reductions between the 450 ppm and the 400 ppm variant are stemming increasingly from the substitution of fossil fuels and less from additional energy efficiency improvements (see also Table 6-17).

Table 6-14: Yearly investment for mitigation measures in efficiency, residential sector, in billion €/a, 450 and 400 ppm variant of the 2°C Scenario, EU27+2, 2020-2050

Region	450 ppm variant			400 ppm variant		
	2020	2035	2050	2020	2035	2050
North	4	5	3	5	6	5
South	16	20	13	18	24	19
East	9	8	7	10	11	12
West	41	50	30	48	61	48
EU27+2	**70**	**83**	**53**	**82**	**101**	**84**

Source: CEPE's results

Table 6-15: Yearly investment for mitigation measures in fuel substitutions, residential sector, in billion €/a, two variants of the 2°C Scenario; European regions and EU27+2, 2020-2050

	450 ppm variant			400 ppm variant		
	2020	2035	2050	2020	2035	2050
North	0.1	0.1	0.1	0.9	0.4	0.2
South	0.3	0.3	0.4	2.9	1.9	1.3
East	0.2	0.2	0.1	1.7	1.4	0.9
West	1.1	0.8	0.8	7.4	5.4	4.8
EU27+2	**1.6**	**1.4**	**1.5**	**12.9**	**9.1**	**7.3**

Source: CEPE's results

Programme costs from public institutions

Of course, the achievements of the 2°C Scenario do not come by itself. To overcome obstacles and market imperfection, public programmes have to be developed in form of information and professional training, by preparing regulation schemes, giving financial incentives to the first movers and by research and development of new technologies. These programme costs have been roughly estimated to range in the order of 10 % of the mitigation investments (see Table 6-16). These programme cost have been transferred to the ASTRA model for the macroeconomic evaluation of the two variants of the scenario.

Table 6-16: Programme costs in residential sector, in billion €/a; European regions and EU27+2; two variants of the 2°C Scenario, 2010-2050

Region	450 ppm variant				400 ppm variant			
	2010	2020	2035	2050	2010	2020	2035	2050
North	0.1	0.4	0.5	0.3	0.1	0.6	0.6	0.5
South	0.3	1.6	2.0	1.4	0.4	2.1	2.5	2.0
East	0.2	0.9	0.8	0.7	0.2	1.2	1.2	1.3
West	0.7	4.2	5.1	3.0	0.9	5.6	6.6	5.3
EU27+2	**1.3**	**7.2**	**8.5**	**5.5**	**1.6**	**9.5**	**11.0**	**9.1**

Source: CEPE's results

6.4 Policy conclusions

Implementation of energy efficiency in buildings poses several unique challenges. Building codes need to be increasingly stringent; they also have to include refurbishing of the existing building stock. Energy audits are a useful tool for pointing out inefficiencies and consist of a detailed survey by a specialist of the energy used in an industrial firm or building. The objective is to provide technical and financial information to investors and building owners about what actions can be taken to reduce their energy bills and at what cost.

Lack of information regarding opportunities and benefits of improved efficiency in residential buildings and equipment slows penetration of these technologies. Information campaigns to foster public awareness and local information centers that provide advice to households and small-to-medium enterprises would help address this problem. Professional training for architects, planners and craftsmen is an important element in order to get out low energy building and passive houses out of their niche markets. and to avoid complaints from building owners.

Households, local authorities and companies are the main investors for building construction and refurbishing. Higher initial investment costs are often a barrier to use of appliances and building components with higher energy performance standards even though lifetime costs of more efficient buildings and equipment are lower because of lower operating costs. There are also principal-agent problems in this sector in which the incentives for builders to reduce prices result in use of low-cost, inefficient components even though consumers' interests would be better served with more efficient dwellings and appliances. Since the most important potential relies in existing buildings at least for EU27+2 countries, access to capital through low interest rate loans is an important argument to motivate refurbishing decisions. such financial mechanisms with the participation of private banks are implanted in several European countries, but should be adopted by all European countries.

Regarding electrical appliances, the following policy measures have been assumed in the projections and are subject to our policy recommendations:

- Establish regularly updated minimum energy performance standards (MEPS) to ensure phase out of inefficient equipment.
- Design labels (comparison labels and endorsement labels) to inform consumers of the costs and benefits of the most and least efficient appliances on the market.
- Encourage well monitored voluntary or negotiated agreements with appliance manufacturers to enhance the overall efficiency of products.
- Support research and development, including encouraging manufacturers to integrate energy efficiency considerations into the early stages of product design.

To conclude: very active energy efficiency policy is needed by all European countries regarding residential buildings, as the re-investment cycle of buildings is extremely long (40 to more than 60 years). Many politicians are hesitant to follow this policy line as home owners and users are voters. They may be convinced accepting more ambitious efficiency an renewables policies by stressing the life cycle cost of buildings, homes and factory buildings.

Finally, the results of the scenario projections clearly show the important role efficiency improvements: while 370 Million tonnes of direct CO_2 emissions would be emitted in 2050 in the Reference Scenario, almost 170 Million tonnes (or 45 %) are reduced by efficiency improvements and more than 60 (17 %) by fuel substitution in the 450 ppm variant (see Table 6-17). This contribution to the reduction target changes in the 400 ppm variant, where total emission reductions are almost 340 Million tonnes (or 91 %) where energy efficiency contributes almost 210 Million tonnes (56 %) and substitution of fossil fuels about 130 Million tonnes (35 %) in 2050. This result of a relative shift towards renewable energies reflects the fact that marginal cost of mitigation by efficiency improvements increase more following very ambitious targets than renewables that still have an enormous potential to reduce their cost by learning and economy of scale effects.

Table 6-17: Impact of different policies and scenario drivers in direct CO_2 emissions in Mt CO_2/year, residential sector; two variants of the 2°C Scenario, 2020-2050

	450 ppm variant					**400 ppm variant**			
	2010	**2020**	**2035**	**2050**		**2010**	**2020**	**2035**	**2050**
Reference Scenario	460	431	412	371	**Reference Scenario**	460	431	412	371
+climate change	0	0	5	12	+ climate change	0	0	5	12
+efficiency	-3	-45	-133	-168	- efficiency	-3	-49	-154	-208
+substitution	-7	-24	-52	-62	- substitution	-7	-72	-127	-131
450 ppm total	450	362	232	153	**400 ppm total**	450	310	136	45

Source: CEPE's results

7 The service (tertiary) and the primary sectors in Europe

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The service sector, also referred to as the tertiary sector, includes the public sector and the non-industrial/manufacturing (private) sectors such as public administration, education and health, bank and finance, trade. Next to some infrastructure services such as street lighting, most of the energy in the service sector is used in buildings. The service sector of Europe in 2005 had a share of 58% in employment, 35% in total electricity demand, 13 % in total final energy demand, and a somewhat lower share of direct CO_2 emissions due to the relatively high shares of natural gas use and district heat supply (Jochem et al. 2007, Eurostat). In line with traditional approaches in energy bottom-up modelling, this section also covers the primary sector, which includes agriculture, forestry, fishery etc.

The future energy demand of the service sector has been projected until 2050 using detailed bottom-up models which explain structural changes and their impact on energy demand more clearly than aggregated models. Non-electric applications, particularly space heating, on the one hand and electric applications and building technologies such as lighting, cooling and ventilation and others, on the other hand, are treated separately as these energy uses depend on different – sometimes diverging – drivers of the bottom-up model such as floor area, number of employee or value added. Energy demand that is used outside buildings was estimated similarly.

However, data availability may be poor for some sub-sectors and European countries and the many assumptions which then have to be made to compensate for missing empirical data may partly offset the advantage of higher differentiation. As in the ADAM M1 report on the reference case (4°C), the building sector's adaptation to climate change (2°C) in each of the 29 European countries was taken into account.

7.1 Challenges and objectives of the analysis

The objectives of the analyses and projections in the service sector were the following:

- (1) The projections up to 2050 should provide a realistic picture of the bottom-up drivers of energy demand in the service sector in relation to the developments in terms of the economic drivers such as value added, increased floor area and number of employees in each country.
- (2) The projections include the impacts of a high adaptation scenario (Reference Scenario) and of an intensive mitigation scenario (called the 2°C Scenario) on energy

demand, energy efficiency, as well as on the costs and investments associated with adaptation to climate change or mitigation of climate change. The energy demand is broken down into fuel and electricity demand, of which the energy demand for cooling is reported separately.

- (3) Finally, the two scenarios should give a brief outline of the policies needed to achieve the mitigation targets or to adapt to the changing climate in Europe.

The challenges involved in the analysis and projections were determined by the objectives and the available data and models. Data for Central and Eastern European countries were often lacking and had to be estimated; the models had to be disaggregated and the influence of changing temperatures on heat demand or air conditioning had to be determined. Finally, the investments in and cost changes of adaptation and mitigation measures had to be calculated to provide data for the macroeconomic analysis performed using the ASTRA model.

7.2 Methodology and assumptions

The modelling of the energy demand of the service sector in Europe is based on the energy demand model SERVE of the Centre for Energy Policy and Economics (CEPE) of ETH Zurich, a detailed bottom-up model for the service sector of Switzerland. It was developed in the 1990s and has been used by CEPE on behalf of the Swiss Federal Office of Energy (SFOE) in the elaboration of new energy scenarios for Switzerland. It includes a cohort model of both the building and the heating system stock and models the electricity demand by categorizing the buildings according to their level of technological equipment which develops over time, as does the specific energy consumption due to technical progress. Detailed accounts can be found in Aebischer et al. (1996), Aebischer and Schwarz (1998), and Aebischer et al. (2007a). For the European case pursued in the ADAM project, an adjusted and simplified approach is followed (called SERVE-E). The basic structure of the approach, which is typical for bottom-up models, can be described as follows:

$$energy = \sum_{i,k} quantity_{i,k} \cdot specific\_demand_{i,k}$$

Where *quantity* denotes a quantitative (mostly physical) driver (e.g. floor area), *specific_demand* denotes the energy demand per unit of quantitative driver (e.g. square metre), *i* the economic sector or sub-sector (see below), and *k* the energy carrier, respectively. The choice of the quantitative driver depends on data availability and the underlying processes of energy use (heating, ventilation, lighting). In the building sector, energy use is mostly related to floor area, which is in turn related to economic drivers represented by indicators such as floor area per employee and value added per employee. Regarding buildings, both the quantitative drivers and the specific energy demand are structured into different cohorts of new (as from 2005) and existing buildings and into unchanged and refurbished buildings (see the ADAM model description report for more details).

The structure of the electricity demand module is similar to that of the heat demand module of SERVE, i.e. the demand for electricity is determined as the product of the specific electricity demand per floor area multiplied by the floor area.

The model SERVE-E differentiates between the following six service sub-sectors:

- Commerce/trade (distribution and warehousing, retail)
- Finance (banks and insurances)
- Hotels, restaurants (including catering)
- Education (schools, universities, research)
- Health (hospitals, social services)
- Others (other commercial offices, public buildings, sport and leisure, transportation infrastructure[12] etc),

Moreover, SERVE-E covers the primary sector which includes agriculture, forestry and fishery, which represents a commonly adopted sectoral breakdown of bottom-up models.

Most data and studies of energy demand for buildings target the residential sector. For this reason, we refer to the chapter on the residential sector for a more detailed discussion about the assumptions.

The main quantitative drivers are floor area and the unit energy consumption (per floor area) for both heating and electricity. The floor area of the service sector is derived from the number of employees, imported from the scenario boundary conditions (see Chapter 2) and from estimates for the future development of the sector-specific floor area per employee.

The number of employees is driven by the value added of the sectors, importing results from E3ME (up to 2030) and ASTRA (relative growth as from 2030) for the Reference Scenario, and the relative change of ASTRA for further iteration in the two mitigation scenarios (450 ppm and 400ppm targets). The number of employees rises in almost all sectors of nearly every country up to 2030. According to the model E3ME, however, there are quite noticeable differences between the EU 15+2 and the new EU-12 Member States (NMS) and between the various sub-sectors. For instance, the number of employees in the sectors commerce/trade and

[12] Regarding transportation, the energy use of buildings (train stations, air ports etc.) and infrastructure (e.g. street lighting, ventilation of tunnels) is included in the service sector, whereas the energy use of cars, buses, trucks, trains etc. is covered by a separate model (ASTRA).

finance increases in the NMS, but decreases in the EU 15+2, whereas the opposite trend applies to the health sector: increasing employees in the EU 15+2 and mostly decreasing in the NMS. After 2030, the relative growth is based on the results of ASTRA, which indicates a reduction in the number of employees in all sectors for both country groups (EU 15+2, NMS), mostly by between -10% and -15%.

It is assumed that, in the long run (up to 2100), there is a tendency for the floor area per employee to reach a similar level in every country. This long-run level is sector-specific and determined by cost-cutting trends (less labour). In some sectors, such as banking and administration, this means less floor area per employee. In other sectors, such as wholesale, retail, hotels etc., this means an increase of floor area per employee (the number of employees here is reduced due to efficiency gains and structural changes, for instance from small retail shops to large commercial centres), see D1 Chapter 6.4.1 for a more detailed description.

Apart from energy demand on the level of useful or final energy, SERVE-E also models substitution effects between different energy carriers. Such substitution effects mainly occur regarding heating energy demand, but in the long term, other energy services such as cooling, cooking or drying (e.g. laundries in hotels or hospitals) might also be subject to energy carrier substitution effects.

In the next two sections, details about the specific assumptions are given, differentiating between heating (space heat and hot water and process heat) and associated fuel energy demand (section 7.2.1) and specific electricity-based energy services (section 7.2.2).

7.2.1 Heating and fuel energy demand

7.2.1.1 Energy efficiency for heating in the service and the primary sector

The service sector improvements of space heating on the one hand, and hot water and process heat on the other are assumed to be similar to those of multi-family houses (see Chapter 6.2.1), taking into account adjusted shares of heating and hot water and process energy demand. The improvements due to the retrofitting of buildings, building technologies, and heating systems result in improvements in terms of the unit energy demand (energy demand per square metre) of between 44% in the case of hotels and restaurants and 59% in the case of offices (in banks and finance, and in other services, public administration, etc.) in the 450 ppm scenario variant (see Table 7-1). In the case of the more ambitious scenario variant, the specific energy demand improvement varies between 54% and almost 70%. Again, the highest efficiency gains are assumed to take place in sectors with the highest share of space heating.

To illustrate these assumptions: An overall reduction of about 50% is achieved if 70% of buildings are each improved by 70%, and an overall reduction of 70% is obtained if almost 90% of buildings are each improved by almost 80%. Such improvements are, in principle, achievable using today's building technology and retrofit practices (see, for instance, Jakob et al. 2006). The assumptions become even more realistic if the techno-economic progress of the next forty years is taken into account. High performance insulation materials, ventilation and other systems with very efficient heat recovery and energy-efficient windows are currently entering the market and will play a prominent role in an ambitious mitigation scenario. Also, control technologies are becoming more and more relevant which allow user-specific energy services (e.g. occupancy, daylight and indoor air quality controls) and avoid energy consumption without use (see for instance Brunner et al. 2008).

Although there is little published evidence regarding fuel energy efficiency in the primary sector (agriculture, forestry etc.),[13] it can still be assumed that there are considerable energy efficiency potentials available at negative or low costs (Urge-Vorsatz and Metz (2009). Such potentials are assumed to be exploited in the mitigation scenario over the next decades. These include, for instance, a more efficient energy use in glasshouse horticulture due to heat management systems, e.g. with heat recovery and intermediate storage (EEAP-NL, 2007), more fuel-efficient farm machinery, particularly tractors. Due to the lack of evidence and following a conservative approach, no differentiation was made between the two scenario variants.

Table 7-1: Fuel energy efficiency improvements in different sub-sectors of the service sector in the two variants of the mitigation scenario relative to the Reference Scenario

	450 ppm mitigation scenario variant		**400 ppm mitigation scenario variant**	
	2035	**2050**	**2035**	**2050**
Trade	30%	50%	37%	62%
Bank, finance	46%	59%	52%	68%
Hotel, restaurants	32%	44%	38%	54%
Education	45%	57%	51%	67%
Health	43%	56%	49%	65%
Other	46%	59%	52%	69%
Agriculture	21%	32%	21%	32%

Source: CEPE's assumptions

13 Urge-Vorsatz and Metz (2009) state that the "contribution of energy efficiency measures in the agricultural sector to climate change mitigation is under-researched".

7.2.1.2 Fuel shares in the service sector

The fuel share assumptions are similar to the residential sector. However, because of the lack of data, electric heating is considered together with other electricity demand. For the two scenarios, we adopted some generic rules (see Table 7-2) which eliminate coal demand in the final energy demand of the service sector and reduce the oil, district heat and natural gas shares by 65%, 35% and 20%, respectively, in the 450 ppm scenario variant compared to the Reference Scenario. In the more ambitious 400 ppm scenario variant, structural change is assumed to be significantly more pronounced: Oil is displaced by nearly 80%, district heat by 50% and natural gas by 75%.

The assumptions about the remaining energy carriers were differentiated by country to account for their respective conditions. There will be a clear increase in the shares of wood, pellets, heat pumps and solar heat, which replace fossil fuel demand, but because of the large demand-side efficiency improvements, energy demand in absolute terms will increase only in the case of solar energy and heat pumps. In countries with low fossil fuel shares, like the northern countries, the changes are minor: Heat pumps (and also solar heat) will displace the share of fossil fuels, and to some extent also wood, which will be exported to other countries. Note that total wood consumption (of all demand sectors) was kept more or less within the potentials available from European sources (see section 5 on EFISCEN).

Solar heat will have greater impacts (in relative terms) on the southern countries , due in part to the higher insulation, but also due to the relatively high demand for hot water in comparison to winter heat generation.

The demand for biogas is implicitly included in natural gas demand. Because of its limited availability and the potentially high demand, buildings and the transportation sector will compete for biogas (and biomass in general). For this reason, biogas use is not broken down into sectors, but is modelled in the conversion sector.

Overall, the structural change of building energy supply is considerably stronger in the two mitigation scenario variants than in the Reference case. Note that the two scenario variants only differ noticeably after 2010.

Table 7-2: Relative fuel share level in the two mitigation scenarios, general rules

	450ppm scenario variant			400ppm scenario variant		
	2010	**2030**	**2050**	**2010**	**2030**	**2050**
Coal	90%	40%	0%	90%	30%	0%
Oil	95%	65%	35%	95%	52%	21%
District heat	100%	85%	65%	100%	77%	52%
Wood		increasing			`strongly increasing	
Natural gas	99%	90%	80%	99%	63%	24%
Heat pumps (el.)		increasing			strongly increasing	
Propane	100%	100%	100%	100%	60%	40%
Pellets		increasing			strongly increasing	
Solar	102%	110%	133%	102%	132%	186%
Biogas		Not explicitly modeled			Not explicitly modeled	
Others	100%	100%	100%	100%	60%	40%

Source: CEPE's assumptions

7.2.2 Electricity demand in the service and the primary sectors

Regarding technical progress and structural changes, differentiated assumptions were made for different sub-sectors depending on the diffusion of building technologies, energy services and the remaining efficiency potentials. The annual improvements listed in Table 7-3 include the net effects of structural changes, additional energy services and efficiency improvements. Efficiency improvements include measures such as planning, appropriate sizing, and control technologies. In the case of existing buildings, retrofits of existing building technologies are covered such as ventilation and cooling systems, lighting installations etc.. Apart from purely technical improvements, it is also possible to optimise the operation and use of energy services such as computers and lighting. Overall, an improvement of around 50% of the unit energy demand in 2050 is assumed in the case of the 450 ppm scenario, and up to 65% in the 400 ppm scenario compared to the Reference Scenario. These assumptions are based on the findings of our own research (e.g. Jakob et al. 2006), various preparatory studies of the Ecodesign Directive (e.g. Adnot et al. 2003, Rivière, Adnot et al. 2008 regarding ventilation and air conditioning, De Almeida et al. 2008 regarding electric motors, Van Tichelen, Jansen et al. (2007) regarding lighting), and others (e.g. Brunner et al. 2009).

Efficiency measures in the primary sector include more efficient electric motor systems such as those used in irrigation and other pumping systems, conveyors, more efficient HVAC systems for livestock and crop drying systems, and others. For instance, the economic use of solar collectors to reduce hay ventilation was already successfully proven in Switzerland in the 1990s.

Table 7-3: Efficiency improvements (with technical and optimization measures) in the different sub-sectors of the SERVE model: yearly improvement of the Reference scenario; additional improvements in the mitigation scenarios compared to the Reference scenario (yearly and overall in 2050)

	Reference scenario			Additional to the reference scenario					
				450 ppm sc. variant		Diff (*)	400 ppm sc. variant		Diff (*)
	2020-2005	2035-2020	2050-2035-	2035-2005	2050-2035-		2035-2005	2050-2035-	
Trade	-0.6%	-0.4%	-0.2%	-1.5%	-2.1%	-51%	-1.8%	-2.9%	-62%
Bank, finance	-0.6%	-0.4%	-0.2%	-1.6%	-2.4%	-56%	-1.9%	-3.2%	-65%
Hotel, restaurants	-0.4%	-0.2%	-0.2%	-1.4%	-2.0%	-50%	-1.8%	-2.8%	-61%
Education	-0.4%	-0.2%	-0.2%	-1.4%	-2.1%	-51%	-1.8%	-2.9%	-61%
Health	-0.6%	-0.2%	-0.2%	-1.7%	-2.5%	-57%	-2.0%	-3.3%	-67%
Other	-0.6%	-0.4%	-0.2%	-1.5%	-2.2%	-53%	-1.9%	-3.1%	-64%
Agriculture	0%	0%	0%	-1.3%	-1.7%	-45%	-1.6%	-2.5%	-57%
(*) compared to the Reference Scenario in 2050									

Source: Deliverable M1.1, CEPE's assumptions

7.3 Results for the Reference (adaptation) and the 2°C mitigation scenarios

7.3.1 Energy demand and energy-efficiency gains in the service and primary sectors

Whereas the energy demand for fuels, which includes all final energies except electricity, either increases or more or less stabilizes between 2035 and 2050 in most of the countries in the Reference Scenario, it decreases in both the 450 ppm and the 400 ppm scenario variants and to a greater extent in the latter. Generally speaking, the difference between the Reference Scenario and the 450 ppm scenario variant varies between 40 % and 60 % in 2050 (see Table 7-4). In the more ambitious 400 ppm scenario variant, the relative energy-efficiency improvement is larger and varies here between 60 % and 80 % (exceptions apply).

The relative improvements are the lowest in the case of the northern countries. This can be partly explained by the fact that these countries were already more efficient at the outset in 2005.

In the 400 ppm scenario variant, there is a strong tendency to substitute fossil fuel heating systems by renewable energies including heat pumps (see Figure 7-1). Although heat pumps are driven by electricity, which might be generated by fossil fuels, such a combination is still more efficient in terms of primary energy or CO_2-emissons than most other individual heating systems, particularly fossil ones. The mitigation effectiveness of heat pumps is even greater if the electricity used to power them is generated in a carbon-free way which is almost the case in the 450 and the 400 ppm scenarios (see Chapter 11).

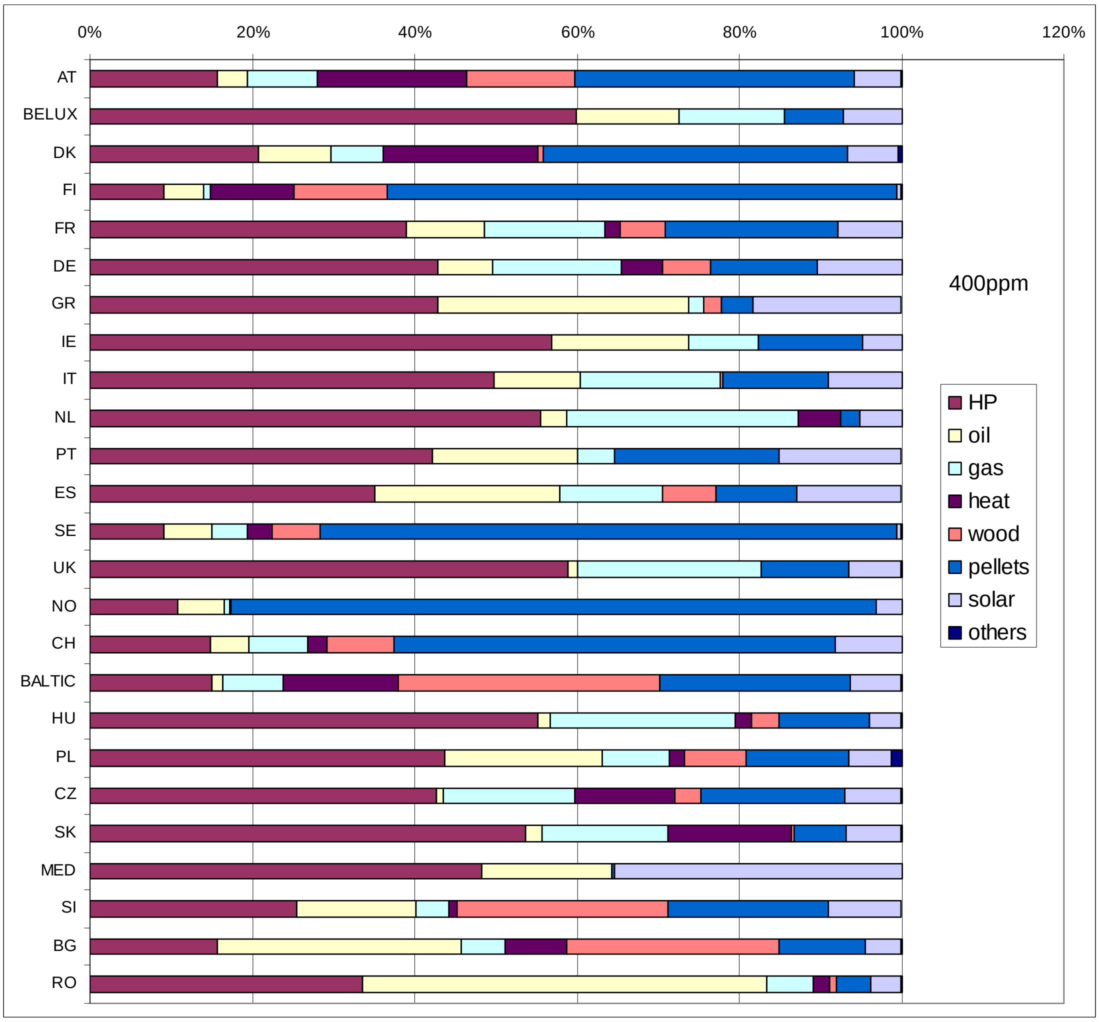
Table 7-4: Fuel energy demand in the service sector of the Reference scenario, and of the 450 ppm and the 400 ppm scenario variants by country and for four European regions 2005 to 2050, in PJ/year

	Reference scenario				450ppm scenario variant				400ppm scenario variant			
	2005	2020	2035	2050	2020	2035	2050	Diff (*)	2020	2035	2050	Diff (*)
Austria	87	91	89	76	82	67	50	-34%	75	53	35	-54%
Baltic States	53	63	66	61	56	47	37	-39%	52	38	25	-59%
Belgium/Lux.	169	175	168	140	142	97	62	-56%	125	64	27	-81%
Bulgaria	18	17	20	18	15	14	11	-40%	14	12	9	-52%
Czech Republic	94	120	120	114	103	78	61	-47%	90	53	32	-72%
Denmark	70	73	75	68	63	51	37	-45%	60	42	26	-61%
Finland	87	80	74	65	72	54	39	-39%	69	47	31	-51%
France	518	524	502	422	430	308	209	-51%	382	228	138	-67%
Germany	913	1053	1026	874	871	639	428	-51%	763	453	249	-72%
Greece	42	36	33	31	31	20	13	-58%	29	18	10	-67%
Hungary	131	159	168	146	138	108	73	-50%	119	69	31	-79%
Ireland	58	71	73	64	57	41	26	-59%	50	29	14	-78%
Italy	439	448	421	354	377	275	190	-46%	332	192	97	-73%
Malta/Cyprus	3	5	5	4	4	2	1	-60%	4	2	1	-68%
Netherlands	405	408	386	329	345	253	170	-48%	308	175	78	-76%
Norway	36	29	26	24	26	18	14	-42%	24	15	11	-56%
Poland	328	390	390	338	327	242	163	-52%	302	186	103	-70%
Portugal	72	112	162	161	83	72	45	-72%	75	63	40	-75%
Romania	90	93	125	127	82	91	75	-41%	80	83	55	-57%
Slovakia	91	141	158	135	117	94	62	-54%	103	62	28	-79%
Slovenia	22	26	25	22	22	16	11	-48%	19	12	8	-63%
Spain	271	317	318	285	262	185	125	-56%	246	158	99	-65%
Sweden	94	109	113	97	97	82	61	-38%	94	71	45	-53%
Switzerland	62	64	63	54	54	44	33	-39%	49	35	22	-59%
United Kingdom	462	533	586	543	443	370	280	-49%	375	235	109	-80%
EU27(+2)	4616	5135	5191	4551	4299	3266	2275	-50%	3840	2396	1324	-71%
North	286	291	288	253	259	204	151	-40%	247	175	114	-55%
South	936	1027	1084	980	854	660	460	-53%	780	527	311	-68%
East	719	900	926	816	762	584	407	-50%	685	420	227	-72%
West	2675	2918	2893	2503	2424	1818	1256	-50%	2128	1273	672	-73%
(*) compared to the Reference Scenario in 2050												

Source: CEPE's results

Renewable energies used for heating purposes mainly include wood-fired energy systems, particularly in northern Europe and the Alpine region of Austria and Switzerland. At the end of the period, pellet systems account for a substantial share of heating in the service sector of these countries. In terms of renewables, wood is complemented by solar energy, especially in the southern countries which have a solar share of 10 % to 20 %, compared to only about half this figure in the other countries. Solar energy may include direct thermal applications that contribute to space heating and other heat demand (e.g. drying) and PV used to drive heat pumps (together with a back-up system).

As far as fossil energies are concerned their share might include conventional or fuel based cogeneration, although cogeneration is not explicitly modelled.



CEPE's results

Figure 7-1: Shares of heating systems (in the service sector, for the 400 ppm scenario variant, in 2050 (all types except direct electric heating)

The share of renewable energy and heat pump heating systems is largest in the ambitious 400 ppm scenario variant (see Table 7-5). Here, the share of fossil fuel energy systems (oil and gas) is reduced by 25%. Note that these are idealised shares. Some of the fossil-fired boilers might be part of combined systems with heat pumps, where fossil fuels satisfy peak demand

and heat pumps the base load heating demand. Such a combination is often more cost-effective and allows the installed power of heat pumps to be lowered. Solar energy is also usually used in combined systems where either fossil fuels or wood boilers provide back-up power during periods with no to low solar availability. The share of wood systems increases from 7% in the Reference Scenario to 11% in the 450 ppm variant and almost triples to 20% in the 400 ppm variant.

Table 7-5: Heating system break down in the service sector of the Reference scenario, and of the 450 ppm and the 400 ppm scenario variants, 2050

	HP (*)	Oil	Gas	Heat	Wood	Solar	Others	Total
Reference scenario	0%	26%	58%	8%	7%	1%	1%	100%
450ppm scenario variant	20%	13%	46%	5%	11%	4%	0%	100%
400ppm scenario variant	43%	10%	15%	4%	20%	8%	0%	100%
(*) Electricity and ambient heat (air or ground source)								

Source: CEPE's results

Contrary to fuel energy demand, electricity demand increases in most countries in the Reference Scenario even after 2035, although then only slightly. However, electricity demand does decrease slightly after 2035 in some countries, mainly in northern and western Europe (see Table 7-6).

Table 7-6: Electricity demand of the service sector for the Reference, the 450 ppm and the 400 ppm scenarios, in PJ/year.

	Reference scenario				450ppm scenario variant				400ppm scenario variant			
	2005	2020	2035	2050	2020	2035	2050	Diff(*)	2020	2035	2050	Diff(*)
Austria	64	76	84	83	66	56	41	-51%	66	53	34	-59%
Baltic States	28	40	49	54	34	32	26	-52%	35	30	22	-60%
Belgium/Lux.	48	58	66	65	52	48	36	-45%	56	50	35	-47%
Bulgaria	23	28	34	36	24	24	18	-49%	24	22	15	-58%
Czech Republic	58	77	84	96	71	61	53	-45%	73	60	46	-52%
Denmark	51	58	66	66	50	45	34	-48%	50	42	28	-57%
Finland	66	73	82	80	64	54	39	-51%	63	49	31	-61%
France	517	666	811	806	580	540	390	-52%	584	502	319	-60%
Germany	480	609	675	661	541	473	347	-48%	561	460	298	-55%
Greece	70	84	103	110	72	69	54	-51%	73	64	45	-59%
Hungary	41	54	66	67	50	48	36	-45%	55	51	36	-46%
Ireland	37	48	55	54	44	43	35	-35%	45	42	32	-40%
Italy	313	385	452	453	352	337	270	-41%	366	336	252	-44%
Malta/Cyprus	11	15	17	18	15	13	9	-48%	15	12	8	-57%
Netherlands	172	188	207	200	170	155	121	-40%	178	158	118	-41%
Norway	93	101	110	108	90	75	54	-50%	89	67	43	-60%
Poland	132	194	241	242	169	171	133	-45%	173	167	117	-52%
Portugal	59	94	143	159	83	101	85	-46%	84	93	67	-58%
Romania	44	59	86	104	52	62	56	-46%	53	60	53	-49%
Slovakia	68	107	132	133	93	90	67	-50%	95	87	58	-56%
Slovenia	11	16	18	16	14	12	8	-49%	15	12	7	-58%
Spain	255	378	464	498	324	304	246	-51%	331	287	208	-58%
Sweden	111	133	156	157	116	105	76	-52%	115	95	61	-61%
Switzerland	57	65	73	73	57	49	36	-51%	58	45	29	-60%
United Kingdom	402	476	561	581	420	385	297	-49%	431	373	263	-55%
North	321	365	414	410	321	279	203	-51%	318	254	163	-60%
South	774	1042	1301	1377	922	909	738	-46%	946	873	648	-53%
East	338	488	590	609	431	414	324	-47%	446	406	286	-53%
West	1776	2185	2533	2524	1930	1749	1302	-48%	1979	1684	1127	-55%
EU27+2	3210	4079	4838	4920	3604	3351	2568	-48%	3688	3217	2224	-55%
(*) compared to the Reference Scenario in 2050												

Source: CEPE's results

In the 450 ppm scenario variant, electricity demand is below its 2005 level either in 2020 (North EU27+2), in 2035 (West Europe, which represents the bulk of the EU27+2), or in 2050 (East and South EU27+2). The electricity demand of the service sector ranges between 45% and slightly more than 50% compared to the Reference Scenario in 2050. In the more ambitious 400 ppm variant, the general pattern is similar to the 450 ppm variant, except for the fact that electricity demand is curbed to a greater extent, by about 5 to 10 percentage points.

Hereafter, the electricity demand for cooling and that for heat pumps are reported separately. These applications are of special interest with respect to adaptation (cooling) and mitigation (heat pumps that replace fossil fuel heating systems). Reporting these applications separately also helps to get a better grasp of the overall results.

In the Reference Scenario, the relative growth of electricity demand is largest in southern countries due to general comfort requirements which call for more cooling, a trend which is reinforced slightly by the changing climate (see Jakob et al. 2008). Although the share of electricity for cooling purposes will increase in all countries, it does so at a significantly higher level in southern European countries, namely by about 45% in the Reference Scenario (compare Table 7-7 with Table 7-6).

In the mitigation scenario variants, the electricity demand for cooling is significantly reduced, namely by almost two thirds, for two main reasons: First, energy efficiency improvements such as more efficient compressors and cooling systems as a whole including free cooling, occupancy control technologies, and others help to lower electricity demand. Indeed, free cooling, that is the use of ambient air or ground, has large efficiency potentials in most countries and for the larger part of the year. Second, climate change is less pronounced – as a result of global mitigation measures. As a result, the shares of cooled floor area are slightly lower and the specific cooling electricity demand per unit of floor area does not increase to the same extent (see Jakob et al. 2008 for more details regarding the relationship between cooling energy demand and cooling degree days).

Table 7-7: Electricity demand for cooling in the Reference scenario, and in the 450 ppm and the 400 ppm scenario variants of four European regions, in PJ/year

	Reference scenario				450ppm scenario variant				400ppm scenario variant			
	2005	**2020**	**2035**	**2050**	**2020**	**2035**	**2050**	**Diff (*)**	**2020**	**2035**	**2050**	**Diff (*)**
North	3	6	8	9	5	5	3	-62%	5	5	3	-62%
South	209	449	604	636	379	335	231	-64%	379	335	231	-64%
East	13	34	51	54	29	29	20	-63%	29	29	20	-63%
West	64	156	225	233	133	125	84	-64%	133	125	84	-64%
EU27+2	288	645	889	931	546	493	338	-64%	546	493	338	-64%
(*) compared to the Reference Scenario in 2050												

Source: CEPE's results

Although significant shares of buildings are assumed to be heated by heat pumps (see Figure 7-1 oben), the total electricity demand for heat pumps (see Table 7-8) remains relatively low compared to the total electricity demand and also compared to the electricity demand for cooling and ventilation (compare with Table 7-7 oben). Such results are consistent with the assumptions regarding increased energy efficiency due to retrofits of the building envelope and of building technologies (particularly ventilation) and regarding the high seasonal energy efficiencies of heat pumps (annually weighted average of coefficient of performance) of 200% to 300%.

Table 7-8: Electricity demand for additional heat pumps in the 450 ppm and the 400 ppm scenario variants of four European regions (compared to the Reference scenario), in PJ/year

	450ppm scenario variant			400ppm scenario variant		
	2020	**2035**	**2050**	**2020**	**2035**	**2050**
North	0	1	2	3	5	4
South	12	31	39	30	54	57
East	10	21	23	30	52	47
West	39	76	83	115	174	152
EU27+2	60	130	147	177	284	260

Source: CEPE's results

Electricity remains the dominant final energy in the service sector in all scenarios and all years (see Table 7-9). This is due to the fact that electricity demand is already very relevant in the base year 2005 and then continues to increase quite strongly in the Reference Scenario. Despite this increase in the Reference Scenario, however electricity demand is reduced in both mitigation scenario variants compared to the base year 2005: by about 20% in the 450 ppm case and by about 30% in the case of the more ambitious 400 ppm scenario variant.

Table 7-9: Final energy demand break down in the Reference Scenario, and in the 450 ppm and the 400 ppm scenario variants of four European regions, in PJ/year.

	Reference scenario				450 ppm scenario variant				400 ppm scenario variant			
	2005	2020	2035	2050	2020	2035	2050	Diff (*)	2020	2035	2050	Diff(*)
Electricity (incl. el. for HP)	3210	4079	4838	4920	3604	3351	2568	-48%	3688	3217	2224	-55%
Heating oil	1707	1556	1409	1166	1289	758	379	-67%	1204	620	243	-79%
Natural gas	2256	2802	2964	2649	2301	1852	1320	-50%	1939	1046	347	-87%
Wood, pellets, chips	140	251	296	317	237	286	323	2%	241	366	467	47%
Solar	6	19	35	38	51	102	117	211%	64	152	181	383%
District heating	384	436	439	349	362	248	133	-62%	337	196	83	-76%
Ambient heat					136	338	429		399	742	753	
Total	7702	9142	9982	9439	7979	6936	5269	-44%	7872	6338	4299	-54%
(*) compared to the Reference Scenario in 2050												

Source: CEPE's results

In relative terms, the biggest decrease is in fossil energies and district heat in both mitigation scenario variants compared to the Reference Scenario and also when compared to the base year 2005. Compared to the Reference Scenario, electricity demand is also reduced quite considerably, namely by roughly 50 %. Conversely, wood energy demand of all kinds more than doubles in the 450 ppm variant by 2050 compared to base year and more than triples in the 400 ppm variant. As a result, wood energy demand is about 50 % higher in the 400 ppm variant than in the less ambitious 450 ppm case.

7.3.2 Changes in costs and investments

In terms of total energy costs, there are several overlapping effects. Some of these effects are cumulative whereas others are compensatory.

- Compared to 2005, energy costs increase in the Reference Scenario due to the general trend of increasing final energy demand and a shift towards electricity, which is more expensive than the other energies.
- To a certain extent the cost increase in the Reference case is due to climate change adaptation since more electricity is consumed for cooling.
- In the mitigation scenarios, the additional costs for cooling are less marked and heating costs decrease.

Until 2020 the adaptation effect is stronger, so that the additional costs for air conditioning are slightly higher than the reduced energy costs of heating. Overall, the reduced heating demand in the mitigation scenarios more than compensates for the increase in electricity demand due to air conditioning, especially in the long term (period 2030-2050). Indeed, in the long run, the current trend towards more air conditioning diminishes so that the reduced energy costs for heating become more relevant (see Table 7-10).

Table 7-10: Fuel and electricity costs (energy expenditures) in the service sector, in billion EUR_{2005} per year.

	Reference scenario				450ppm variant				400ppm variant			
	2005	2020	2035	2050	2020	2035	2050	Diff (*)	2020	2035	2050	Diff (*)
North	15	17	20	19	13	12	12	-38%	13	11	9	-50%
South	35	48	58	59	31	34	31	-47%	31	35	32	-45%
East	12	19	23	24	23	17	16	-34%	23	14	11	-52%
West	88	116	133	133	102	88	77	-42%	100	76	56	-58%
EU27+2	150	201	233	235	170	152	136	-42%	167	136	109	-53%
(*) compared to the Reference Scenario in 2050												

Source: CEPE's results

In addition to the cost differences due to energy expenditures, there are also additional investments made to increase the air conditioned area and to maintain or increase comfort levels. The additional investments due to a warmer climate are based on specific costs found in Rivière, Adnot et al. (2008) for room air conditioning, and on Jakob et al. (2006) for central air conditioning and ventilation installations. The re-investment cycles range from 15 years for room air conditioning to 20 years for central air conditioning.

The investments needed for adaptation amount to 1.5 billion euros per year in the Reference Scenario, but less than half this amount in the two mitigation scenarios (see Table 7-11).

Table 7-11: Investment in adaptation in the service sector, in billion EUR$_{2005}$ per year, , for two warmer climate scenarios: +4 and +2 degrees

	4 degree scenario (reference)				2 degree mitigation scenario (450-400ppm)			
	2020	**2020**	**2035**	**2050**	**2020**	**2035**	**2050**	**Diff (*)**
North	0.13	0.26	0.35	0.39	0.16	0.20	0.16	-58%
South	0.06	0.15	0.22	0.25	0.11	0.15	0.11	-56%
East	0.13	0.24	0.32	0.35	0.04	0.06	0.19	-44%
West	0.21	0.35	0.47	0.50	0.25	0.10	0.17	-66%
EU27+2	0.54	0.99	1.36	1.48	0.56	0.51	0.63	-57%
(*) compared to the Reference Scenario in 2050								

Source: CEPE's results

The mitigation costs are considerably larger than the adaptation costs in buildings of the service sector, namely around 50 billion euros per year for energy efficiency measures of the building envelope (see Table 7-12) and about 0.8 billion euros for investments in fuel substitutions in the 450 ppm variant and 1.3 billion euros in the 400 ppm variant, respectively (see Table 7-13). Investments in fuel substitution are much lower since all the heating systems display similar investment costs (see Jakob et al. 2006), so that only minor differences are assumed.

Table 7-12: Investments in efficiency mitigation measures in the service sector, in billion EUR$_{2005}$ per year

	450ppm scenario variant			400ppm scenario variant		
	2020	**2035**	**2050**	**2020**	**2035**	**2050**
North	3	3	3	3	4	3
South	15	16	12	12	13	10
East	7	6	5	8	7	7
West	20	25	20	24	29	25
EU27+2	46	51	40	48	54	46

Source: CEPE's results

Hence, investments of 50 billion euros per year in mitigation measures (see Table 7-12 and Table 7-13) induce savings of 100 to 130 billion euros in terms of reduced energy costs (compare mitigation scenario variants and the Reference Scenario in Table 7-10 oben).

Table 7-13: Mitigation investments in fuel substitutions in the service sector, in billion EUR_{2005}

	450 ppm scenario variant			400 ppm scenario variant		
	2020	2035	2050	2020	2035	2050
North	0.00	0.00	0.00	0.05	0.02	0.00
South	0.17	0.28	0.26	0.77	0.64	0.33
East	0.07	0.08	0.08	0.41	0.31	0.14
West	0.41	0.53	0.41	2.03	1.73	0.82
EU27+2	0.65	0.90	0.75	3.27	2.69	1.29

Source: CEPE's results

A coherent set of policy measures is needed to trigger these investments. Some of these measures induce almost no programme costs, e.g. mandatory codes and standards for new buildings and building technologies. Alongside such measures, it is expected that additional measures such as education, information and promotion programmes will be necessary to help curb energy demand in the service sector. Overall, programme costs in the service sector are estimated at 4 to 5 billion euros in the 450 ppm scenario variant and 6 to 7 billion euros in the more ambitious 400 ppm scenario variant (see Table 7-14). This represents an average share of 10% to 15% when compared to the mitigation investments.

Table 7-14: Programme costs in the service sector, in billion EUR_{2005}

	450 ppm scenario variant				400 ppm scenario variant			
	2010	2020	2035	2050	2010	2020	2035	2050
North	0.0	0.3	0.3	0.3	0.0	0.3	0.4	0.4
South	0.3	1.6	1.7	1.3	0.4	1.8	2.0	1.6
East	0.1	0.7	0.6	0.5	0.1	0.9	0.9	0.8
West	0.4	2.1	2.5	2.0	0.4	2.8	3.5	3.1
EU27+2	0.9	4.6	5.2	4.1	0.9	5.9	6.8	5.9

Source: CEPE's results

7.4 Conclusions and policy recommendations

As a result of the scenario projections, not only is final energy demand considerably reduced, but also direct CO_2-emissions: by 133 Mt CO_2/year (i.e. by 57%) in the 450 ppm scenario variant (compared to the Reference Scenario) and by about 200 Mt CO_2/year (i.e. by 84%) in the 400 ppm scenario variant (see Table 7-15).

The contributions to the reduction target, i.e. the difference in direct CO_2-emissions between the Reference Scenario and the two mitigation scenario variants, are broken down into the most relevant effects which are climate change, economic impacts, energy-efficiency improvements and substitution effects. Two first two mentioned effects are positive, i.e. emissions of the mitigation scenarios increase rather than decrease assuming that all other factors are unchanged.

Compared to the Reference case, (gross) direct CO_2-emissions increase slightly in the mitigation scenario variants because more heating energy is needed due to a lower rise in the ambient temperature in the mitigation cases. Note, however, that this effect is only minor, namely about 3% of the difference in the case of the 450 ppm scenario variant (4 Mt CO_2/year out of 133 Mt CO_2/year of net reduction) and relatively spoken even less in the 400 ppm case (4 Mt CO_2/year out of about 200 Mt CO_2/year of net reduction) (see Table 7-15). Also, (gross) CO_2-emissions in the mitigation scenario variants increase due to macro-economic effects – if everything else remains unchanged: mitigation measures call for additional investments including engineering and other services which have a positive effect on employment in the sector, too. In 2050, this contributes about 9% additional CO_2-emissions.

Besides these rather minor increases, the results of the scenario projections follow – in qualitative terms – a similar pattern as in the residential sector: In relative and absolute terms, energy efficiency improvements make the biggest contribution in the 450 ppm variant (-130 million tonnes of 158, i.e. 82%million tonnes of gross direct CO_2 emission reductions or 55% of the emissions of the Reference scenario in 2050), while substitution effects are much lower (29 Mt, i.e. 18% of the gross emission reduction or 12 % of the reference scenario). In contrast, the contribution of energy efficiency decreases in the 400 ppm scenario variant to almost 70% of the gross reduction of direct CO_2-emissions (or two thirds of the emissions of the reference level in 2050), whereas substitution effects of all kinds, mainly towards renewable energies, but also towards electricity, increase to 31% (29% of the reference level in 2050).

Table 7-15: Impact of different policies and scenario drivers on direct CO_2 emissions in $MtCO_2$/year in the service sector; two variants of the 2°C Scenario, 2020-2050

	450 ppm scenario					**400 ppm scenario**			
	2010	**2020**	**2035**	**2050**		**2010**	**2020**	**2035**	**2050**
Reference	259	272	270	235	**Reference**	259	272	270	235
+climate	0	0	2	4	+climate	0	0	2	4
+macroeconomic	0	1	11	22	+macroeconomic	0	1	11	22
+efficiency	-2	-36	-96	-130	+efficiency	-2	-39	-112	-154
+substitution	-5	-13	-28	-29	+substitution	-5	-36	-67	-69
450 ppm	253	224	160	102	**400 ppm**	253	198	104	37

Source: CEPE's results

As in the residential sector, these results reflect the fact that the marginal costs of mitigation by efficiency improvements are quite low for a considerable part of the potential (i.e. the marginal cost curve is flat), but then increase quite strongly (steep curve). For this reason, the absolute contribution of energy efficiency is not much larger in the 400 ppm variant than in the 450 variant. Conversely, the costs of renewables are higher to start with, but still have a large potential for cost reduction through learning and economy-of-scale effects.

With regard to the contributions of energy efficiency and substitution effects presented above, it is recommended to base policy measures on both energy efficiency and renewable energy, with an emphasis on energy efficiency.

To a certain extent similar principles apply as in the residential sector, although some peculiarities have to be considered. As in the residential sector, the implementation of energy efficiency poses several challenges, particularly regarding the building envelope and building technologies with long life-cycles. In the service sector, an even larger share of energy, particularly electricity, is related directly to the building (and less to products and appliances as in the household sector). This applies to lighting, heating, ventilation and cooling, which represent large energy shares in this sector, but also to information and communication technologies which have more of a building infrastructure character.

Hence standards, codes and labels which have traditionally focused on residential buildings, i.e. on the building envelope and on thermal energies, need to be extended and adjusted to service sector buildings , particularly to include electricity consuming building technologies.

Also the principal-agent or split-incentive issue is particularly relevant in the service sector, both in the case of constructing new buildings and in the case of operating and refurbishing existing buildings. Incentives are split along the supply chain between companies. The incentives for builders to reduce prices result in the use of low-cost, inefficient components, even though consumer interests would be better served by more efficient buildings and technologies. This issue is even more relevant since the supply chain is quite long. For instance, more than five different companies are needed to design and implement a cooling system and its energy efficiency performance is influenced by even more than this. There may also be different incentives within different departments of the same company (e.g. between the investment and the operations department). Moreover, diverse priority setting and the lack of information about the opportunities and benefits of improved efficiency slows the penetration of these technologies (see Sorrell et al. 2004 for more insights regarding the economics of energy efficiency, especially regarding barriers to cost-effective investments).

A broad portfolio of policy measures such as energy audits that provide technical and financial information to investors and building owners, information campaigns to foster public awareness, local information centres that provide advice to small-to-medium enterprises (SMEs) would help to address this problem. Moreover, specialised, professional training for architects, planners and craftsmen is an important element to address the issue of interactions between different energy services (e.g. between lighting and cooling) and to achieve low energy buildings and passive houses.

Regarding the service sector, the following specific policy measures have been assumed in the projections and are subject to our policy recommendations (see also Jakob 2008):

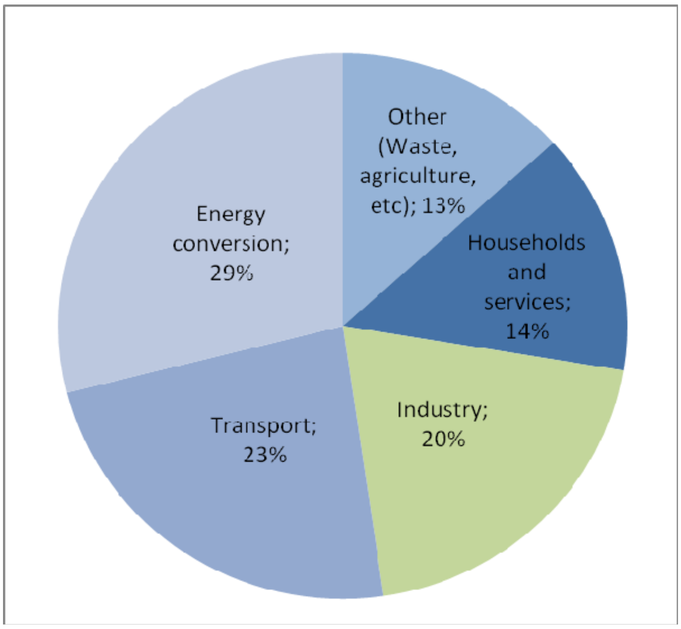
- Establish regularly updated minimum energy performance standards (MEPS) to ensure the phase-out of inefficient equipment and products (e.g. cooling and ventilation systems, cooling appliances, lighting products and systems).
- Encourage integral planning (see Jakob et al. 2006b) and commissioning of new buildings to establish energy-efficient operation.
- Stimulate continuous monitoring and optimisation of building technology operation to avoid energy consumption without use (Brunner et al. 2008).
- Promote the use of renewable energies including ambient air and ground sources in the context of (free) cooling and managing heating and cooling needs (Wellig et al. 2007).
- Design labels (comparison labels and endorsement labels) to inform consumers of the costs and benefits of the most and least efficient appliances on the market.
- Encourage well-monitored voluntary or negotiated agreements with appliance manufacturers to enhance the overall efficiency of products.
- Support research and development, and encourage manufacturers to integrate energy efficiency considerations into early stages of product design.

To conclude: A very active energy efficiency and renewable energy policy is needed by all the European countries regarding buildings in the service sector, as the re-investment cycle of buildings and building technologies is quite long (20 to more than 60 years). It must be stressed that the intensity of policy measures has to be augmented considerably compared to past and present activities in order to be able to achieve the improvements and emission reductions described in this section.

8 Basic products and other manufacturing industry sectors

8.1 Target of analysis

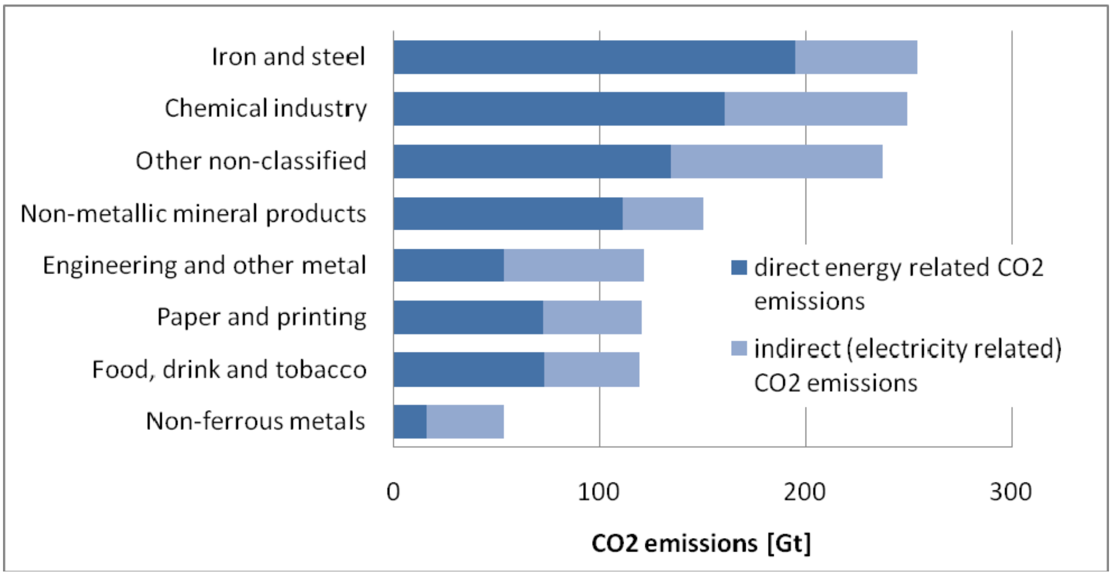
Industry accounted for about 28% of the energy consumption in the European Union in 2005, equivalent to 13.7 EJ. At the same time, GHG emissions amounted to about 1098 Mt CO_2 equivalent, which is a share of 20 percent. While the sectoral shares remained fairly constant over the period from 1990 to 2005, total emissions fell by 15.4%.



Source: EU statistical pocket book 2007/2008

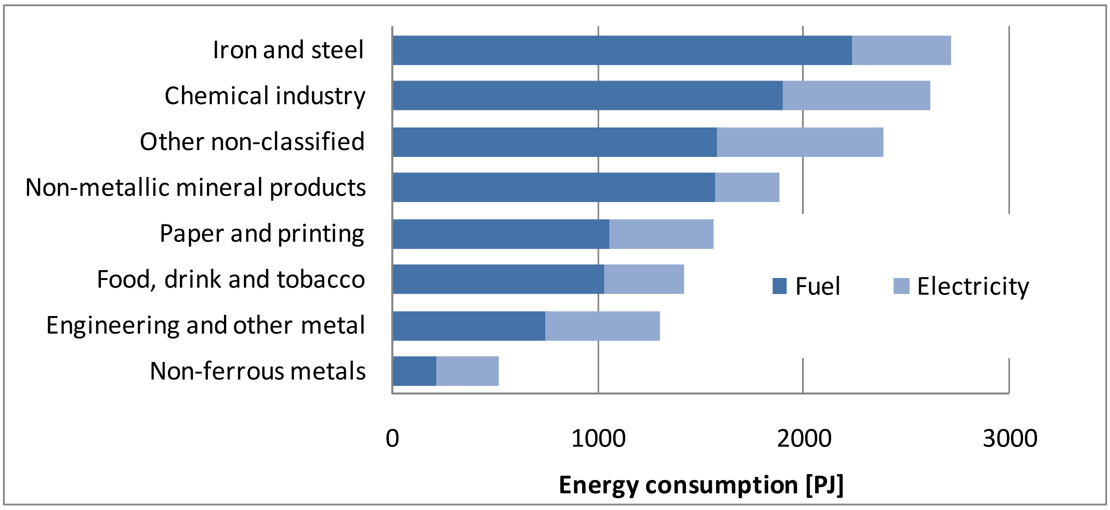
Figure 8-1: GHG emissions by sector (2005, EU27)

Figure 8-2 shows that the iron and steel production as well as the chemical industry are by far the largest CO_2 emitting sectors. Although direct, energy-related, CO_2 emissions are dominant in industry, the indirect emissions related to electricity consumption are also significant. To calculate the indirect emissions, country-specific emission factors were taken into account. Process-related GHG emissions (not from energy conversion), e.g. from clinker burning, nitric acid or adipic acid, are not considered in this figure.



Source: own calculations based on Eurostat

Figure 8-2: CO_2 emissions in industry by subsector (2004, EU27)



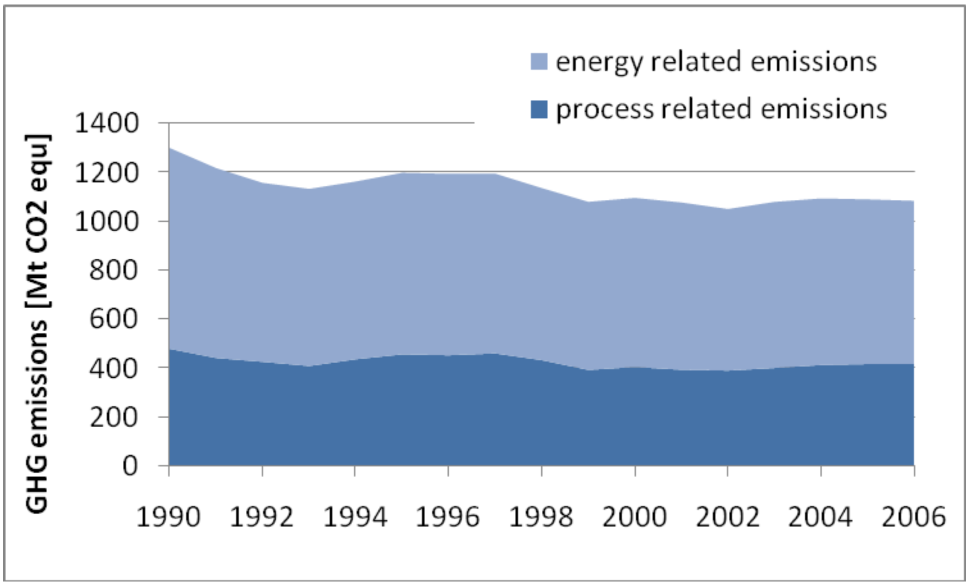
Source: Eurostat

Figure 8-3: Energy consumption in industry by subsector (2004, EU27)

Given the large share of industrial GHG emissions, the importance of this sector for mitigating climate change becomes obvious.

Although industrial GHG emissions are about 15% below the 1990 level in 2006, there has been no clear trend towards an autonomous emission reduction over the last years and emissions have remained more or less constant. Industrial restructuring in Eastern Germany and Eastern Europe during the nineties had a significant impact on reducing GHG emissions.

This chapter analyses the technical as well as policy options to reduce emissions and bring them in line with a long-term sustainable development. The applied approach is a bottom-up model of energy demand and CO_2 emissions based on the most energy-intensive industrial processes as well as the most relevant cross-cutting technologies (such as ventilators, pumps, compressed air etc.) and their related saving options. The main drivers of energy demand in industry are the value added as well as the physical production of energy-intensive products like steel, cement and paper.



Source: EU statistical pocket book 2007/2008

Figure 8-4: Development of direct GHG emissions in the EU27 industrial sector

In our analysis of the industrial sector we distinguish between energy-efficient technologies and abatement options that are available industry-wide and can be applied to different processes on the one hand and, technologies that are very process-specific on the other. The former are referred to as cross-cutting technologies (CCT) in the following. We also make a distinction between CCT that consume electricity – mainly motor systems – and CCT that produce heat (steam and hot water boilers, combined heat and power generation).

8.2 Technologies and assumptions

8.2.1 Cross-cutting technologies electricity

In contrast to the household or even the commercial sector, electricity is used for a much wider variety of purposes and appliances in industry. Most systems are individually designed according to the characteristics of production processes which often differ between companies.

Figure 8-5 gives an overview of the possible uses of electricity in industry. The figure shows some example applications.

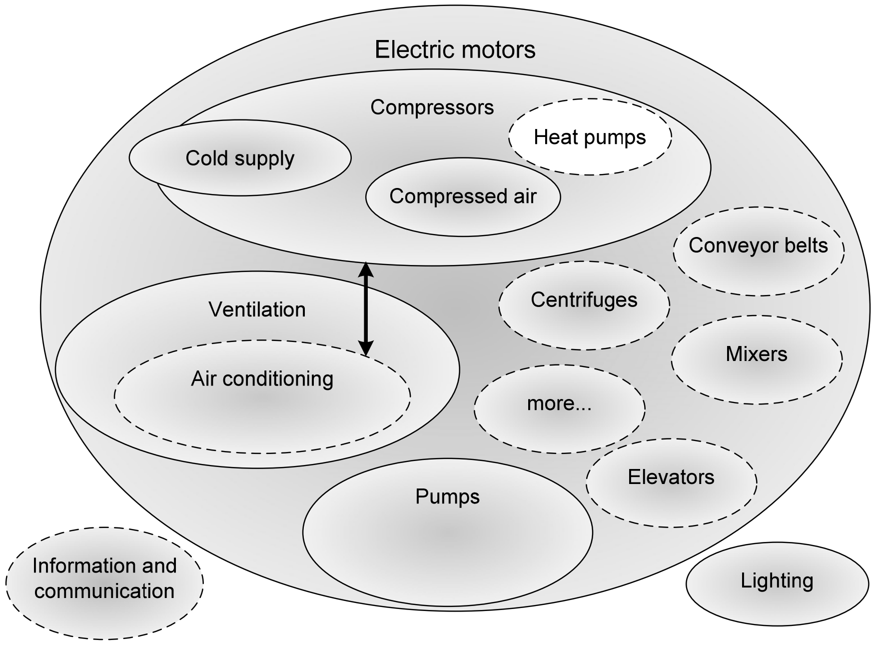


Figure 8-5: Chosen cross-cutting technologies (CCTs) in industry – system boundaries

By selecting the most relevant technologies, it is possible to cover a larger part of the electricity demand in the model. Depending on the country-specific structure of industry, the share of CCT changes slightly, but is on average about 70 % of total industrial electricity consumption, if electric motors and lighting are considered to be CCT. The shares of each CCT considered, the relevant saving options and their potentials are important inputs to the scenario calculations. As there is no single data source available which covers all the most important cross-cutting technologies, we combined several sources and filled any data gaps with our own estimations.

As electric motors make up the biggest share in electricity demand, five of the six CCTs considered are electric motor systems, while the sixth is lighting. Thus electric motors play a central role in our assessment of efficiency potentials and they do have a large potential, which is available relatively short-term and at very low or mostly negative costs. The selected technologies are described below.

Pumps represent the CCT with the highest share of industrial electricity demand, estimated to be about 12 % in Europe. The paper industry, in particular, has a very high share of pumps in its electricity consumption, mainly used for pulp and water pumping (Sulzer Management, (Winterthur) 1997). Saving potentials for pumps were taken from the Ecodesign study lot 11

(Falkner 2007) and a previous study that also assessed pump systems on a European level (ETSU et al. 2001).

Fans are mainly used in industry for cooling, drying, suction cleaning or the ventilation of rooms (Hoffmann, Pfitzner 1994). A huge variety of different fan types are utilised in industry, which all have varying efficiencies. According to Radgen (2002), they account for about 9 to 17 % of the electricity demand of industrial branches. Again, the Ecodesign study from lot 11 provides detailed stock and saving potentials data (Radgen et al. 2007).

Compressed air is used in industry for a variety of different applications, like pneumatic drives for tools, fogging and varnishing as well as for suction and cleaning. The advantage of compressed air in comparison to the direct use of electricity is mainly its flexibility (Fraunhofer ISI 2003). Thus, for many applications, compressed air is often preferred, despite its higher electricity demand. A detailed analysis of the stock of compressed air systems in Europe including possible saving options and their potentials was conducted by Radgen et al. (Radgen, Blaustein 2001) and provides the basis for our calculations.

Cooling systems are not as widespread through industrial branches as other CCTs are. They are mainly used in the food sector, for cold storages and refrigerators, and in the chemical sector for low temperature processes.

Other motor appliances represent all motor systems not covered by the systems described above. This group is very heterogeneous and includes, for example, conveyors, centrifuges, elevators and mixers. Despite its heterogeneity, the saving potentials related to the core motor system (meaning the motor and its drive) can still be estimated. Our estimation is mainly based on the study by Almeida et al. (Almeida et al. 2001) for the stock of electric motors in the EU and by Almeida et al. (Almeida et al. 2000) for saving potentials in variable speed drives, i.e. motor drives. Up to the year 2020, the savings estimated in the Ecodesign lot 10 report (Almeida et al. 2007) were used.

Lighting systems in industry either use fluorescent lamps or high intensity discharge lamps (HID), representing between 37 and 63 %, respectively, of the total electricity demand for lighting in Europe (IEA 2006). Thus industrial lighting is clearly far more efficient than residential lighting.

To show the saving potentials and their costs not only in relative terms but also in absolute values for the industrial sector of a whole country, we needed to identify the absolute energy demand of each of the considered motor systems. Therefore we estimated the share of every motor system in the total electricity demand of each industrial subsector (see Figure 8-6), based on the literature cited above.

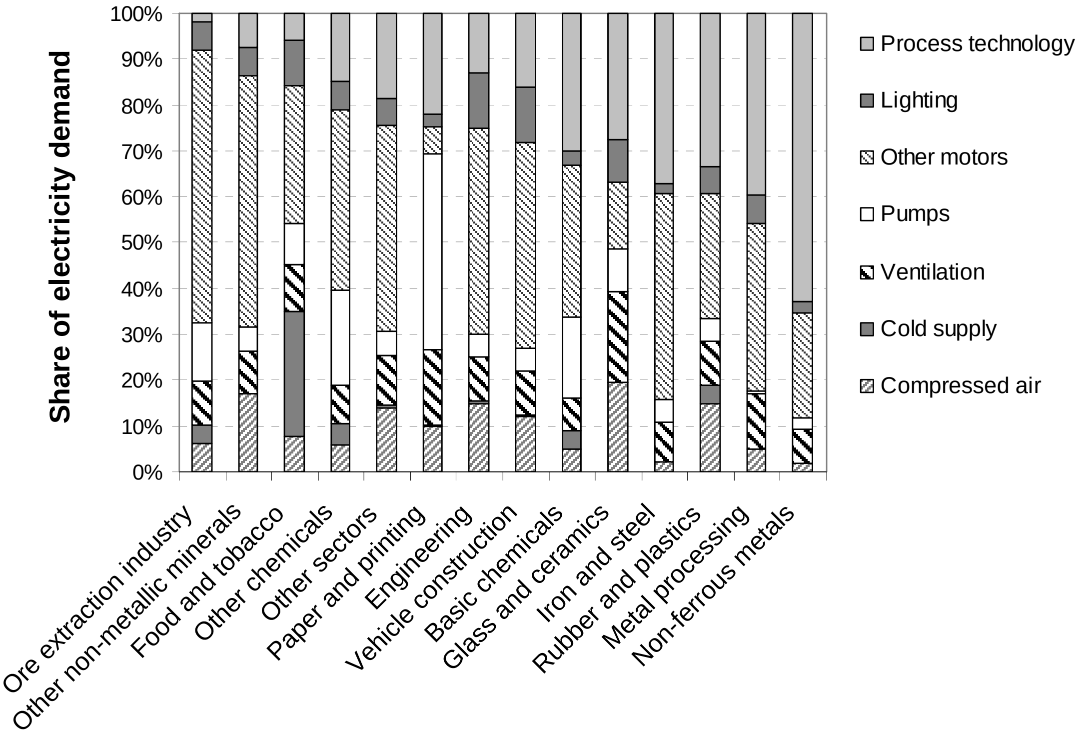


Figure 8-6: **Share of cross-cutting technologies by sector**

To assess the saving potentials, we related specific saving options to any one of the cross-cutting technologies; for example, the repair of air leakages in compressed air systems. As we included about 50 saving options in total, it is not possible to describe each of them in detail; instead, the following summary indicates which type of options were considered.

As shown, most of the cross-cutting technologies considered are *motor systems*. Due to the similarity of motor systems, there are several saving options that can be applied to more than one system. Examples include using higher efficiency motors (Almeida et al. 2007), or directly coupling the motor and the application it is driving, which avoids the friction losses of a belt-driven system. The assumptions made about the further diffusion of highly efficient electric motors are summarised in Figure 8-7, which shows how the market share of each motor class develops over time.

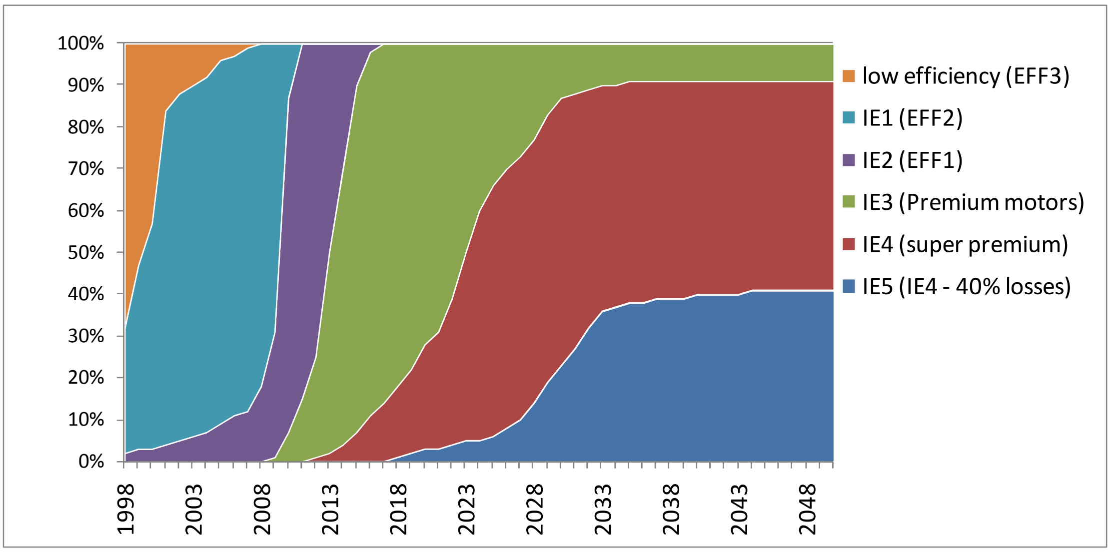


Figure 8-7: Market share development of motor efficiency classes in the 2°C scenario

The selection of high efficiency *pumps, fans* and *compressors* also leads to considerable savings (Radgen et al. 2007). The optimisation of the ductwork is another often very effective saving option; this is especially the case in compressed air systems, where only small leakages in the pipes may be responsible for huge energy losses (Radgen, Blaustein 2001 p. 49). In all systems, there is the possibility to lower so called 'standby losses' by improving control systems that are related to the real demand of an energy service. Control systems are especially interesting in combination with a variable speed drive, which is an inverter that controls the input frequency to the motor and thus also the motor's rotation speed depending on the load (Almeida et al. 2000). Variable speed drives are especially efficient in pump systems that are often controlled using a valve, which decreases the flow of a fluid by increasing friction in the pipe, but leaves the rotation speed of the motor constant.

For *pumps*, there is the possibility to smoothe the surface by coating it with glass or resin to reduce friction losses and also increase durability (Gudbjerg, Andersen 2007).

Lighting systems are somewhat different to the presented motor systems. A lighting system for discharge or fluorescent lamps consists of a lamp, a ballast, cables, control mechanisms and light fixture. All these components influence the efficiency of the entire system.

Using electronic instead of magnetic ballasts can decrease the electricity consumption by about 25 % at constant luminous efficacy (Meyer et al. 2000 p.111).

Besides technical improvement options, a high saving potential can be realised using improved and demand-related control systems. These may be quite simple like more and better located light switches and time switches, or more complicated systems including motion detectors and photometers that allow the illumination level to be adjusted to the actual demand (Carbon Trust 2006, p.5).

For some CCTs, comprehensive analyses of saving potentials exist, like the study conducted by Radgen et al. (2002; 2001) on compressed air and ventilation systems. In these cases, the literature values were taken and extended slightly as well as updated.

The resulting saving potentials are shown in Figure 8-8. Each bar represents one CCT system and shows the aggregated savings of this system possible from applying the best available technology. Although the technical savings are shown, most of these are actually cost-effective as well and all will be exploited in the 450 ppm scenario. In contrast, in the Reference Scenario, only 30% of these potentials are exploited on average, varying by technology and saving option.

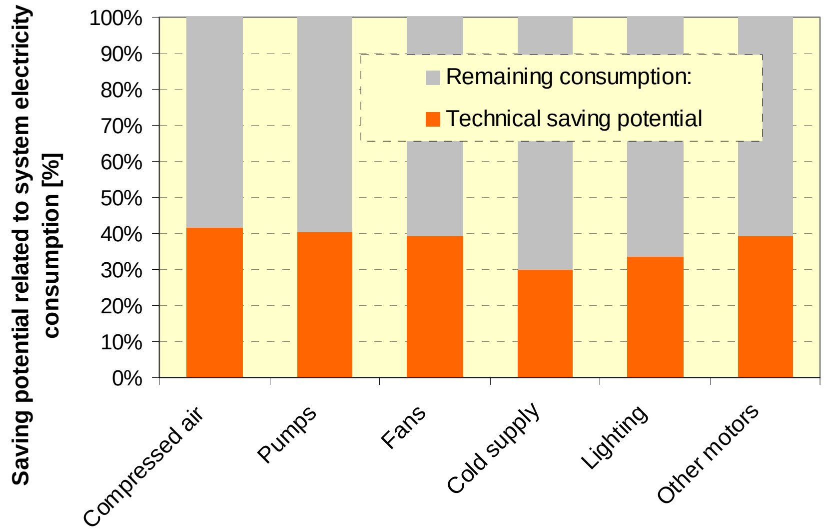
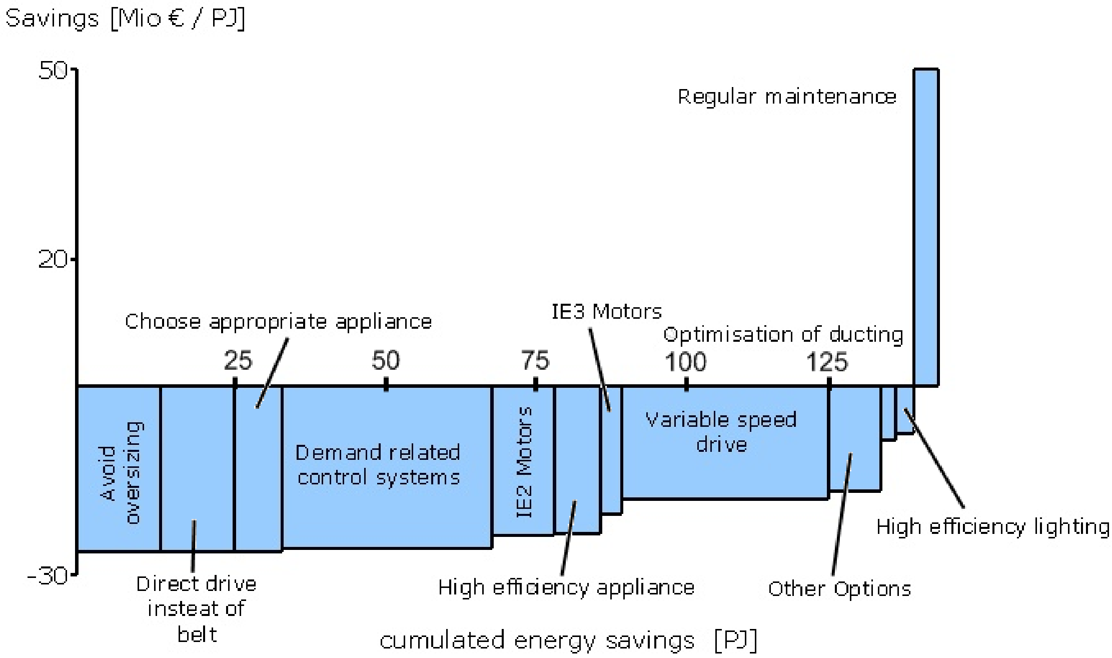


Figure 8-8: Relative long-term technical saving potential by application

As the lifetime of many of the motor technologies ranges between 10 and 25 years, this is also the time horizon assumed for the diffusion of efficient technologies through the stock. The reason for this slow diffusion is the general assumption that technologies are not replaced before their end of life, i.e. the conventional life-cycle is not disturbed. This significantly decreases costs, because only the additional costs for the efficient technology compared to the standard technology are taken into account, but it also slows down the market diffusion.

How cost-effective the cross-cutting technologies are is shown by the exemplary cost curve for Germany in Figure 8-9. The average costs of nearly all the efficiency measures are negative, which means the options are cost-effective. However, because of the heterogeneity between companies and countries, some of the options might not be cost-effective in all applications even though they are cost-effective on average.

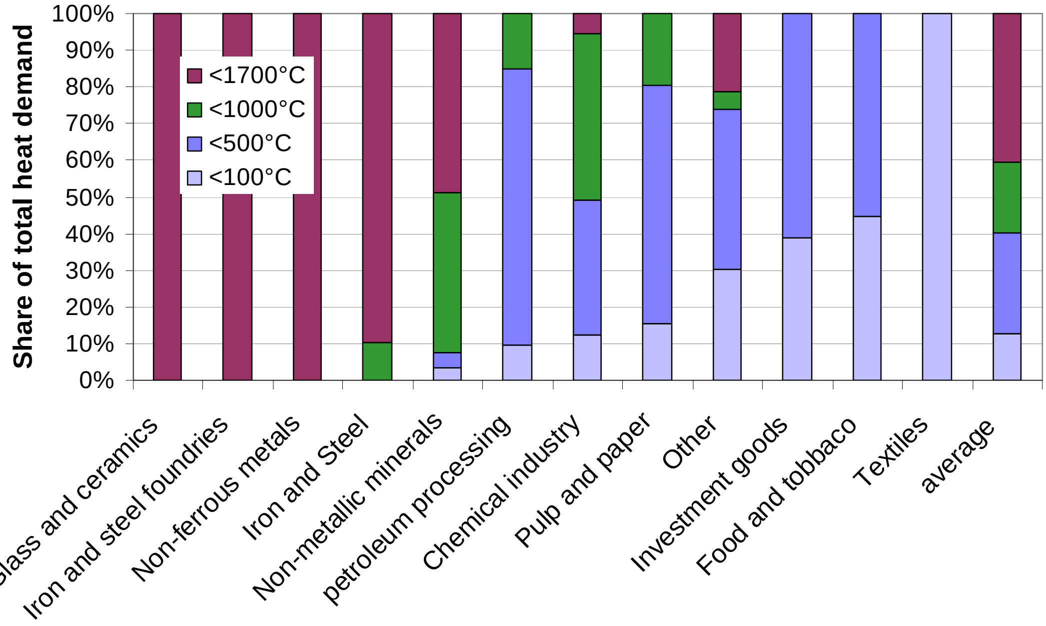


Source: Fleiter (2008)

Figure 8-9: Exemplary cost curve for aggregated saving options in electrical cross-cutting technologies (Germany, 2030)

8.2.2 Cross-cutting technologies heat and steam

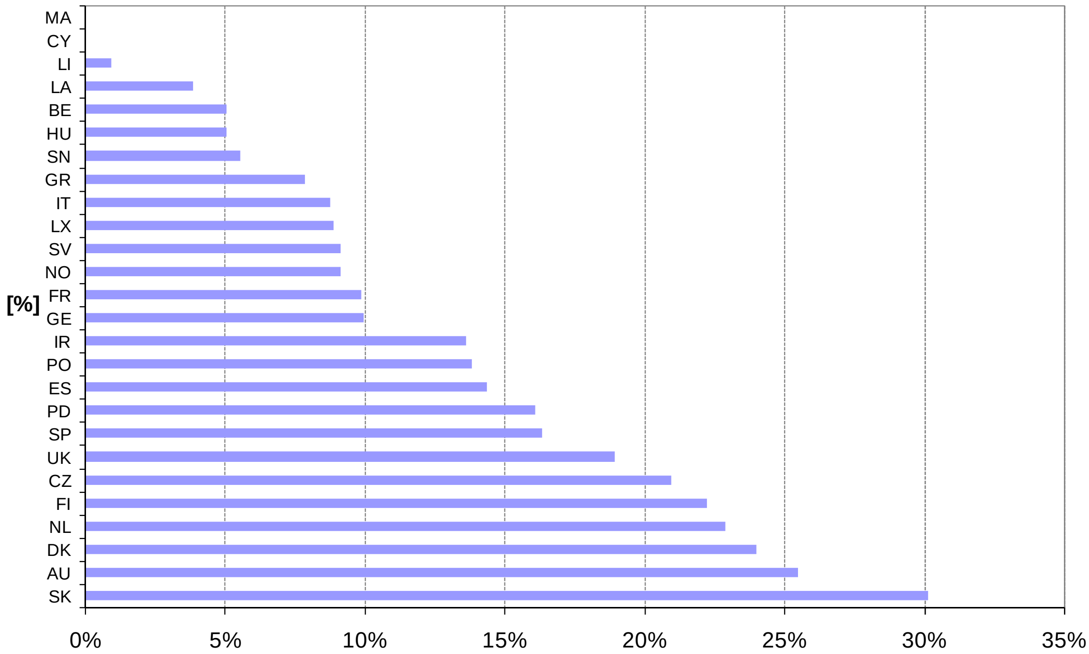
Heat is used in industry for a wide variety of different purposes. While, in some cases, heat with a temperature of less than 100°C is sufficient, other branch-specific processes require temperatures far above 1000°C. While low temperature levels can be supplied by ordinary boilers, for the high temperature processes, industrial furnaces specially designed for certain processes are necessary. Figure 8-10 illustrates in detail which temperature levels are needed in which industries. Although the calculation methodology is based on a rather old study by Hofer (1994), the method used is still valid as the main processes in industry have not changed considerably since then.



Source: Source: own calculations based on Hofer (1994)

Figure 8-10: Heat demand by industrial sector and temperature level

A variety of different technologies are applied to generate CHP in Europe, which are presented briefly based on the overview given by (IZT Institute for Futures Studies and Technology Assessment gGmbH et al. 2002 p.44). Steam turbines are the classical and most used CHP technology, either as backpressure or condensing turbines, which are flexible with regard to the fuel input. The disadvantage of steam turbines is the relatively low electrical efficiency of below 20 percent. In industrial CHP, gas turbines are more common because of their high reliability and large range of power. They have a higher electrical efficiency but are restricted to gaseous and liquid fuels, traditionally natural gas. The highest electrical efficiency can be reached with combined cycle gas turbines (CCGT), which are a combination of a gas turbine followed by a steam turbine. Their main advantage, their high efficiency of more than 40 percent, led to a tripling of electricity production in CCGT in the EU-15 between 1994 and 1998 (Eurostat 2001 p. 14), while in the same period, the electricity production from steam turbines remained constant. A remarkable increase in electricity generation was also able to be observed for internal combustion engines. These are mainly applied in smaller units and for more decentralised and flexible purposes.



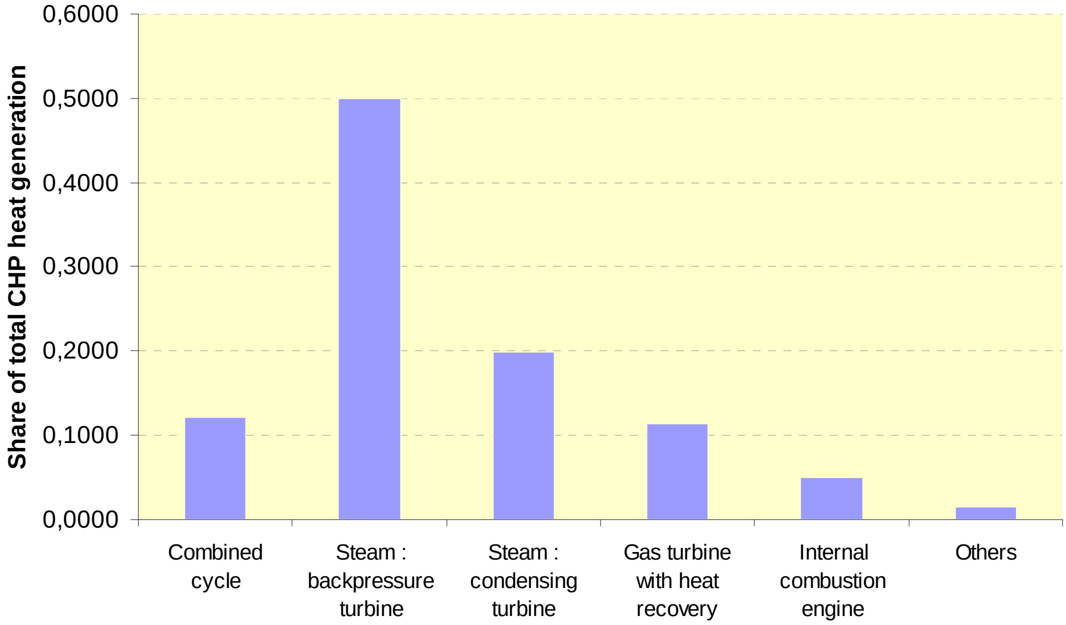
Source: (Danko 2005)

Figure 8-11: Share of industrial CHP electricity output in total industrial electricity demand in European countries (2004)

Source: (Danko 2005)

Figure 8-12 shows the share of heat generation of each of these technologies in total CHP generation. Unfortunately, only aggregated data was available for public and industrial (autoproducers) CHP heat generation. In industry, the share of steam turbines might be lower and the use of gas turbines might be more extensive than shown in this figure.

All these technologies permit heat production with a maximum temperature of around 500°C. Thus, their application is bounded by the temperature pattern of heat demand. As shown in Figure 8-10, heat below 500°C is concentrated on certain sectors, which, consequently, have the highest potential for further CHP utilization.



Source: (Danko 2005)

Figure 8-12: Heat generation by CHP technology

Two general groups of saving options are implemented in heat generation: improved diffusion of combined heat and power, replacing separate generation of heat and electricity, and improved efficiencies in separate as well as combined heat generation. Both are explained in the following.

In this paragraphe, the first option, the increased diffusion of CHP plants, which substitute separate heat and electricity generation systems is described. As an upper threshold for CHP diffusion, it is assumed that CHP can only be applied to the share of heat demand with a temperature below 500°C. CHP technologies producing heat above 500° are not available so far but might become so in the future. One option could be the solid oxide fuel cell (SOFC) that produces heat up to 900°C, which would clearly increase the potential for CHP applications in the industrial sector. It is assumed that the share of heat generation from CHP in relation to total heat consumption in industry increases from 15% in 2004 to 32% in 2030 in the 2° scenario, whereas it increases to 20% in the Reference scenario. After 2030, only slight increases in the CHP share are assumed.

Calculating the energy savings due to faster CHP diffusion is a methodologically crucial aspect. In this modelling approach, we applied a methodology in accordance with Eurostat (Eurostat 2001) which calculates the savings by comparing the CHP system with an alternative system that might have been used if the CHP unit had not been built. The saving potential is defined as the difference between the primary energy demand of each system. Consequently, the choice and definition of the alternative system - the system that was replaced by the CHP plant – has considerable influence on the results. If, for example, the alternative system is a modern Combined Cycle Gas Turbine (CCGT) for electricity generation with an efficiency of about 60 % and a modern boiler for heat generation with an efficiency above 90 %, the savings allocated to the substitution by CHP are rather small if not negative. In contrast, if the efficiencies of an average power plant are assumed to be the alternative to CHP, the savings allocated to CHP are considerably higher, and may even be overestimated. In our calculations, we assumed an alternative system that produces electricity with an efficiency of 45 % and heat with an efficiency of 85 %.

The second group of energy savings is related to an improved energy efficiency of all heat supply technologies. All the technologies mentioned above have a potential for energy efficiency improvements. It is important to consider the fact that the model works using the average efficiencies of plants already in operation, which also includes rather outdated technologies with low efficiencies.

This approach is based on the most recent Eurostat statistics on CHP (Danko 2005). The remaining saving potential is calculated as the difference between the average efficiency of a certain heat production technology in a certain country and the highest efficiency of the same technology in all countries. As the differences in average efficiencies between countries are high, the saving potentials also vary greatly. If there was no data available for one country, the average efficiencies of either the EU-25 or the EU-15 were taken.

The emission reductions in industry achieved in the 450 ppm scenario and the 400 ppm scenario are mainly managed by significantly increasing the deployment of solar thermal heat supply. So far, solar thermal energy has hardly been used in industry, and if it is applied, then usually to provide space heating. Its integration into industrial processes is still at the R&D stage (Werner W et al., 2008). Solar thermal is especially applicable in the low temperature range (below 250°C), which is mostly found in the food industry, the pulp and paper industry, textile industry, chemical industry and, to a lower extent, also in some other branches (compare Figure 8-10). To account for company- and process-specific barriers to solar thermal energy, we assumed certain thresholds for the low temperature heat demand able to be supplied by solar energy. These are lowest in the paper industry (max. 20 %) and highest in the food industry (max. 80%). Evacuated tube collectors were assumed to be the main technology, but they can be seen as being representative for other solar technologies as well. Especially in the Nordic countries, evacuated tube collectors have significant advantages compared to standard flat plate collectors and they also allow heat to be provided at a higher temperature level (up to 170°C) (Werner W et al., 2008). We assumed the best moment to install a solar heating system is when the conventional heating system reaches its end of life and has to be replaced. The solar system is sized so that it provides all the solar heat needed by the process during summer periods, when irradiation is highest. Consequently, in winter, considerable gaps exist between solar heat supply and heat demand (depending on the country-specific irradiation). Thus, the conventional heating system, i.e. gas or oil boiler, is still needed, also as a backup for short-term variations in solar irradiation. As a result, the solar fraction varies between 75% in southern countries and 60% in northern ones, resulting in different solar heat potentials. This further reduces the above mentioned company- and process-specific technical restrictions.

Taking these assumptions into account, the resulting diffusion of solar thermal heat in industrial sectors is shown in Figure 8-13. The share of solar energy throughout industry rises to about 9% in 2036 and remains at this level until 2050.

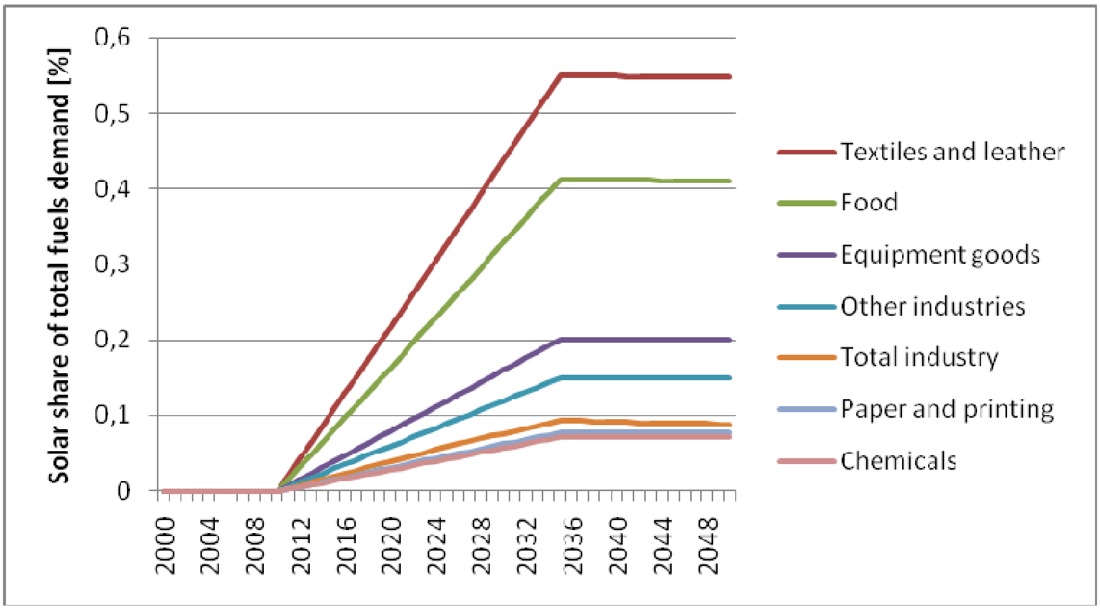


Figure 8-13: Share of solar heat in total fuel demand by industrial sector in the 400 ppm scenario for the EU27

Investment costs also vary strongly among countries, mainly due to the differing solar collector area needed to provide the same amount of heat. The solar irradiation varies between 1060 kWh/m²a in Ireland and 2008 kWh/m²a in Malta. Consequently, in countries with lower irradiation, a considerably larger collector area is needed, which increases the total costs of solar heat supply. For the calculations, the following technological characteristics of evacuated tube collectors were used: 45% efficiency, investment costs of 400 euros per m² which are assumed to be reduced to 260 euros per m² in 2050 and an average lifetime of 25 years (German Solar Energy Society, 2005).

8.2.3 Process-specific technologies

In contrast to the above mentioned cross-cutting technologies, process-specific technologies are related to explicit industrial branches or processes. They represent options to improve the efficiency of certain processes (e.g. papermaking, steel casting or rolling, clinker burning for cement production, etc.). Due to the large variety of different processes applied in industry, it is not possible to discuss all the assumptions and technologies considered in detail. Instead, we will give an overview of the processes considered and describe some of the most interesting options with the potential to induce large savings.

Industrial sectors can be further divided into the most energy-intensive processes for which data is needed about production statistics and forecasts as well as specific energy consumption. By considering physical production values and the specific energy intensity for each process, its bottom-up energy demand can be calculated. But as the amount of data needed for the calculation increases considerably when extending the bottom-up calculations to further processes, only the processes with the highest energy consumption are included (compare Figure 8-14).

Iron and steel	Non-ferrous metals	Paper and printing
Sinter	Primary aluminium (Hall-Heroult)	Paper
Blast furnace	Secondary aluminium	Mechanical pulp
EAF	Aluminium further treatment	Chemical pulp
Rolled steel	Primary copper	Recovered fibres
Coke oven	Secondary copper	
Smelting reduction	Copper further treatment	
Direct reduction	Primary zinc: imperial smelting	
	Zinc: galvanizing	
Glass	**Cement**	**Chemicals**
Container glass	Clinker burning-dry	Chlorine-Hg (mercury)
Flat glass	Clinker burning-semidry	Chlorine-Membrane
Other glass	Clinker burning-wet	Chlorine-Diaphragm
	Quarrying	Polypropylene (PP)
	Raw material preparation	Polyethylene (PE)
	Cement grinding	Polyvinyl chloride (PVC)
	Lime milling	Ammonia
	Gypsum milling	Carbon black
		Cracker

Figure 8-14: Processes by sub-sector implemented in the model

As is the case for the cross-cutting technologies, saving options also exist for the process-specific technologies that have the potential to improve energy efficiency and thus lower the specific energy demand. In total, about 80 distinct saving options are considered and allocated to the relevant processes. Some examples are described below:

- For the production of chlorine in the chemical industry, three main technologies can be used: the diaphragm process, the mercury process and the membrane process. Of these, the membrane process is least energy-intensive and a clear trend is currently observable and is considered in the calculations that this process will continuously substitute the mercury process, which will be banned in Europe by 2020.
- The energy intensity of cement production is directly related to the clinker / cement ratio, i.e. the amount of clinker used to produce a fixed amount of cement. The more clinker substitutes, such as fly ashes or granulated blast furnace slag are used, the less energy-intensive is the production of cement. In our calculation, a considerable increase of clinker substitutes is considered, leading to an average clinker factor of about 71 % in 2030.
- For the production of steel, two main processes are used: the blast furnace and the electric arc furnace (some others play a minor role in Europe). Of these two, the electric arc furnace requires enormous amounts of electricity so that a shift towards this process would greatly increase electricity demand while at the same time decreasing the demand for fuels. In terms of primary energy, however, this shift still induces significant savings.
- In aluminium production one can distinguish between primary and secondary aluminium. The production of primary aluminium is very energy-intensive, because electrolysis is used. For the secondary aluminium production route, which is far less energy-intensive, recycled aluminium is used. Also here, a shift towards secondary (recycled) aluminium is an important option to lower energy demand for aluminium production. However, there are clear restrictions to the technology in terms of the available amount of scrap.
- In most steel mills, steel finishing is a multi-step process that includes intermediate products and reheating to allow for the next rolling step. Emerging technologies like thin slab or strip casting allow significant reductions in the production steps required, by already casting the steel in a form that is closer to the final form (thin products) and thus requires less rolling and preheating. Using this technology instead of the traditional continuous casting, about 50% of the energy demand could be saved. According to IEA (2007), it is applicable to one quarter of the worldwide steel production.
- Black liquor is a by-product of chemical pulp production and is normally burned in a recovery boiler to produce electricity and heat for the pulp mill. The use of the conventional recovery boiler has several drawbacks, like poor efficiency, poor environmental performance and difficult handling. Therefore, ongoing R&D activities are trying to commercialise a process in which the black liquor is gasified before being converted into electricity or liquid fuels. This so called black liquor gasification technology would result in significantly higher conversion efficiencies and also reduce the environmental impacts as well as the process risks. As a result, a chemical pulp

production plant could develop towards a biorefinery that also produces surplus electricity.

8.2.4 Carbon Capture and Storage

In the 2°C scenario, carbon capture and storage (CCS) is considered for the most CO_2 intensive processes in industry, which comprise clinker burning in cement production and the blast furnace route in steelmaking. It is considered to the same extent in both the 400 ppm and the 450 ppm variants, but is not considered at all in the Reference Scenario. Although, CCS is already being discussed as an option for CO_2 abatement in other sectors such as the pulp and paper industry (Hektor, Berntsson 2007), we do not apply it to other sectors, as steel and cement making are by far the most CO_2 intensive processes, and thus, the diffusion of CCS will concentrate on these processes first.

State-of-the-art cement production accounts for about 1 t CO_2 emissions per tonne of cement produced. These emissions can be equally divided into process emissions (related to the chemical process) and those related to the combustion of fuels. In primary steel production, the average European blast furnace plant emits about 1.5 t CO_2 / t pig iron. Spain, Italy and Germany account for about 50% of the CO_2 emissions related to cement production, while Germany is by far the largest emitter of steel-related CO_2.

According to the Community independent transaction log (CITL), the emissions of both processes amounted to about 319 Gt CO_2 in the year 2008 in the EU27 (187 Gt due to cement and lime and 132 Gt due to pig iron and steel production). Both processes are covered by the EU ETS and future reductions will be strongly driven by the prices of emission allowances.

The available data on total emissions varies depending on the source. While the Community independent transaction log presents 132 Mt CO_2 equivalent from pig iron and steel production for 2008, the UNFCCC greenhouse gas inventory cites 89 Mt CO_2 equivalent for 2006. Differences may arise from how blast furnaces or converter gas are accounted.

The assumptions about the technological possibilities are based on first results from the ULCOS[14] project, which focuses on emerging technologies for low-emission steel production. We assume a capture coefficient of 50% for CCS, which starts to diffuse through the market in 2030. Up to 2050, the capture coefficient increases to 85% and 84% of steel and cement plants will be equipped with CCS. Thus, we assume that CCS is first implemented in the power sector and only after sufficient experience has been gained is it introduced in industrial

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[14] https://www.ulcos.org.

processes. The main policy driver for the development is the EU ETS and the price of the emission allowances.

Investment costs for CCS in industrial processes are still difficult to assess as so far, not even demonstration projects have been conducted. Thus the cost estimations are based on the expected costs for CCS in power plants. We calculated abatement costs of 60 Euro / t CO_2 in 2030 which decrease to 30 Euro / t CO_2 in 2050.

The main driver behind falling CO_2 emissions, which already occur in the case without CCS, is the physical production of cement and steel. Here, improvements in material efficiency lead to a 10% lower demand for steel and 13% lower demand for cement in 2050 compared to the Reference development. Further details on the production development are presented in Chapter 5 on material efficiency.

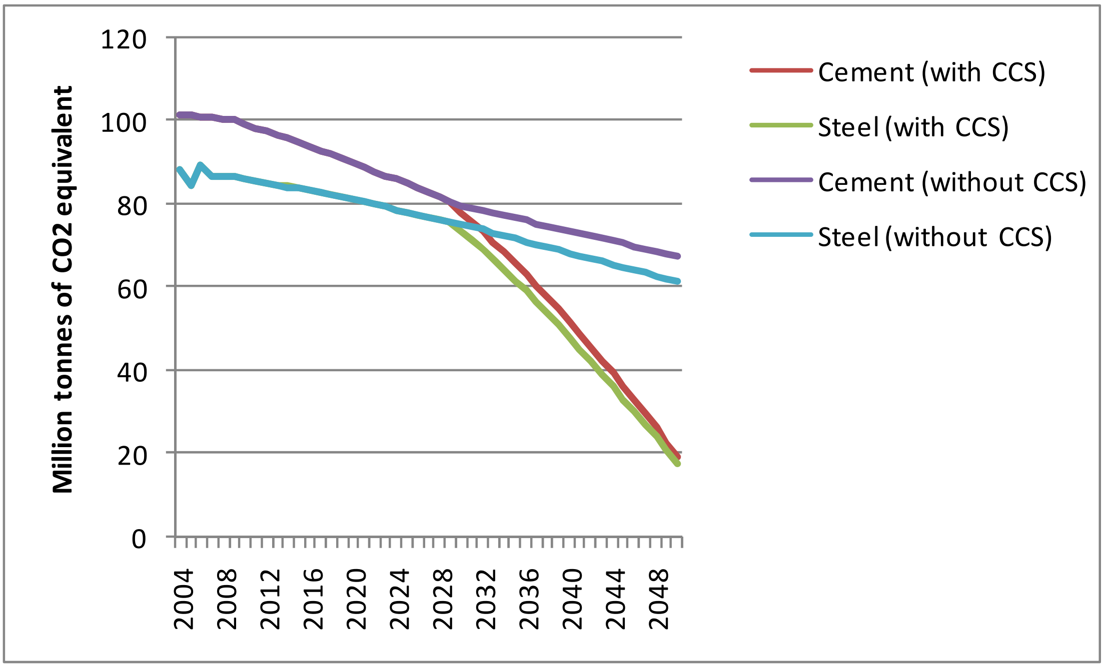

Figure 8-15: Development of CO_2 emissions in cement and steel depending on the introduction of CCS

8.3 Model rationale and limits

The ISIndustry model belongs to the class of energy system or bottom-up models, which means the calculation is based on technological information about distinct conservation options and industrial processes. Regarding the technological foundation of the model, we distinguish between process-specific technologies and cross-cutting technologies. Blast furnaces in steelmaking are one example of the former; these are sector- and even process-specific. In contrast, cross-cutting technologies are widespread across very different industrial sectors. Examples include electric motors or lighting equipment, which are applied throughout all industrial sectors.

For process-specific technologies, the main driver is the projection of physical production (e.g. tonnes of crude steel from blast furnaces). The 40 most energy- and greenhouse gas-intensive processes were considered separately in the model. For each of these processes, the specific energy consumption/GHG emissions and the physical production output per country are modelling parameters.

Although individual cross-cutting technologies are usually smaller in size than the process specific technologies, there are huge numbers involved due to their widespread application and so they are responsible for a huge share of industrial electricity consumption. Electric motor systems and lighting account for more than 70% of industrial electricity consumption. They are implemented in the model as a share of the total sector's electricity consumption and their main driver is the projected development of value added per industrial sector.

The model's level of technological detail allows the long-term industrial energy demand to be simulated based on distinct technological energy efficiency options while considering the main economic trends. However, it becomes increasingly difficult to predict technological developments for the longer term. In particular, after 2030, new options will probably arise that are completely unknown at present and at the same time, most of the known options will have more or less fully diffused throughout the stock by then. Consequently, we assumed that technological change continues beyond 2035 at the same pace as before. Thus, in the period from 2035-50, estimations are mainly based on extrapolation of efficiency improvements rather than detailed modelling of technology developments. One exception here is the diffusion of CCS and the deployment of solar thermal heating systems, which were modelled separately up to 2050.

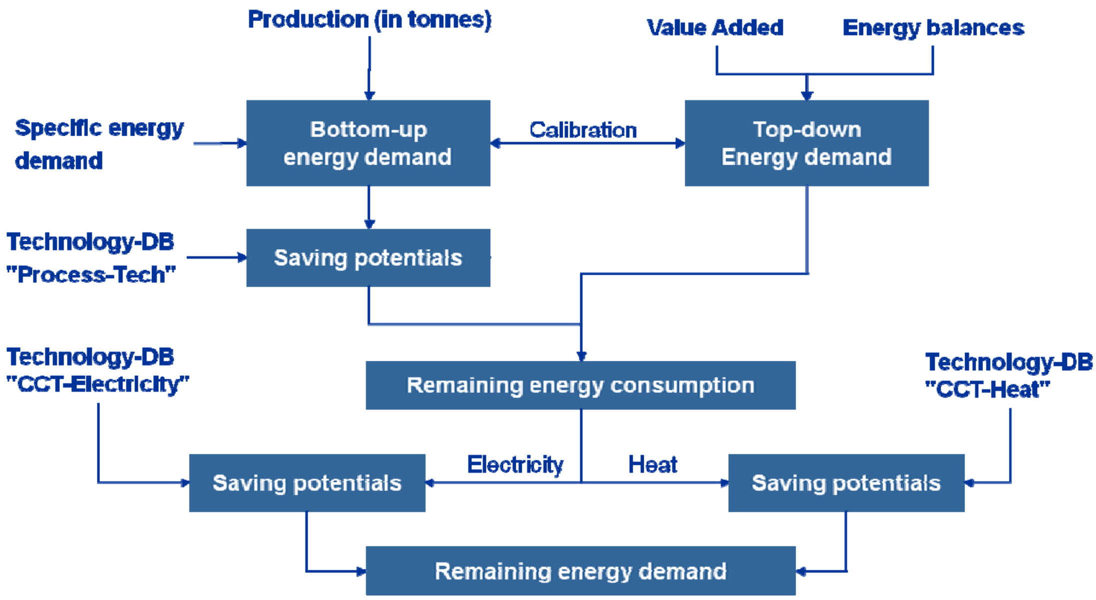

Figure 8-16: Simplified structure of the ISIndustry model

As already mentioned, one advantage of the modelling approach is the high level of technological detail considered in the calculations. In contrast to top-down approaches, the bottom-up approach used clearly shows which technologies can contribute to the long-term development. Nevertheless, there are still limitations to this approach which are described below:

- In general – and especially in the very heterogeneous industrial sector - bottom-up modelling is not able to consider all the options or technologies. It has to concentrate on the main options or can attempt to group less influential options, but there will always be certain (possibly less costly) abatement options that are not covered by such an approach.
- Although we calculated additional investment costs on a technology basis, these costs are often rather indicative and in reality may vary substantially. In particular the costs of industrial process innovations are difficult to estimate. Often it is not clear if these are exclusively energy efficiency innovations or have other co-benefits, like increased production capacity, which should also be accounted for.
- As bottom-up models are very data intensive, data quality is also a very crucial aspect for the quality of the results.
- As our approach considers distinct technologies and their characteristics such as investment costs, specific energy consumption of lifetime, by definition, only known technologies can be considered. But it is highly probable that promising new technologies will be developed in the next decades. Furthermore, the more innovative a technology is, the less reliable its data becomes. Costs for emerging technologies which are still

basically concepts or research projects cannot be estimated without considerable uncertainty.

8.4 Results of scenarios

The results show large CO_2 reductions in both the 450 and the 400 ppm scenarios. While total EU CO_2 emissions fall from 651 to 235 Mt in the 450 ppm scenario, they decrease even further down to 210 Mt in the 400 ppm scenario. These reductions are equivalent to relative changes of -33% and -40% for the year 2050, respectively, compared to the Reference development. The reductions are mainly achieved by improvements in production efficiency, carbon capture and storage for steel and cement production as well as resource and material efficiency, leading to a lower demand for energy-intensive products. The additional reductions in the 400 ppm scenario in comparison to the 450 ppm scenario are mainly due to large scale diffusion of solar thermal heating in industrial low-temperature processes.

The already substantial reductions in CO_2 emissions in the Reference case are mainly driven by inter-industrial structural changes and significant energy efficiency improvements. While the shares of the large energy-consuming sectors like iron and steel, the chemical industry or the non-metallic minerals decrease in many countries, the less energy-intensive sectors increase.

Table 8-1: Comparison of industrial CO_2 emissions between scenarios [Mt]

Country or country group	Reference Case			2°C Scenario (450ppm)			2°C Scenario (400ppm)		
	2005	2020	2050	2020	2050	Diff.	2020	2050	Diff.
EU27	651,53	558,43	349,94	509,57	235,71	**-33%**	485,94	209,99	**-40%**
North*	35,62	32,64	21,63	29,95	14,80	**-32%**	28,13	12,30	**-43%**
South*	326,97	260,81	156,21	237,64	100,03	**-36%**	226,49	88,42	**-43%**
East*	84,31	71,51	54,31	64,57	36,58	**-33%**	61,67	32,31	**-41%**
West*	211,44	198,72	121,35	182,37	87,10	**-28%**	174,42	79,28	**-35%**

*North: Denmark, Finland, Norway, Sweden; South: Spain, Italy, Portugal, Greece, Bulgaria, Malta, Cyprus, Romania; East: Baltic States, Czech Republic, Hungary, Poland, Slovakia, Slovenia; West: Austria, Luxembourg, Belgium, Netherlands, France, Germany, Ireland, Switzerland, United Kingdom

Source: ISIndustry calculations

In contrast to (direct) CO_2 emissions and fuel demand, electricity demand grows slightly in the EU27.

Table 8-2: Comparison of electricity consumption between scenarios [PJ]

Country or country group	Reference Case			2°C Scenario (450ppm)			2°C Scenario (400ppm)		
	2005	**2020**	**2050**	**2020**	**2050**	**Diff.**	**2020**	**2050**	**Diff.**
EU27	4155	4292	4300	3544	2723	**-37%**	3544	2723	**-37%**
North	579	655	847	546	541	**-36%**	546	541	**-36%**
South	2241	2186	2187	1809	1386	**-37%**	1809	1386	**-37%**
East	364	448	440	368	281	**-36%**	368	281	**-36%**
West	1155	1226	1116	1011	689	**-38%**	1011	689	**-38%**

Source: ISIndustry calculations

Table 8-3: Comparison of fuel consumption between scenarios [PJ]

Country or country group	Reference Case			2°C Scenario (450ppm)			2°C Scenario (400ppm)		
	2005	**2020**	**2050**	**2020**	**2050**	**Diff.**	**2020**	**2050**	**Diff.**
EU27	9857	8412	5497	7631	3716	**-32%**	7641	3741	**-32%**
North	977	876	642	777	416	**-35%**	776	417	**-35%**
South	4778	3747	2322	3403	1521	**-34%**	3408	1533	**-34%**
East	1211	1034	806	932	545	**-32%**	932	549	**-32%**
West	2997	2832	1789	2592	1285	**-28%**	2599	1292	**-28%**

Source: ISIndustry calculations

Table 8-4: Comparison of final energy consumption split by industrial subsector between scenarios [PJ] for EU27

Country or country group	Reference Case			2°C Scenario (450ppm)			2°C Scenario (400ppm)		
	2005	2020	2050	2020	2050	Diff.	2020	2050	Diff.
Chemicals	2431	2388	1812	2124	1337	**-26%**	2122	1334	**-26%**
Rubber and Plastic	267	229	182	195	125	**-31%**	195	125	**-31%**
Primary metals	3132	2729	2107	2446	1210	**-43%**	2470	1244	**-41%**
Non-metallic minerals	1899	1448	967	1328	734	**-24%**	1328	734	**-24%**
Paper and printing	1678	1761	1564	1435	890	**-43%**	1434	893	**-43%**
Food	1340	1229	868	1068	549	**-37%**	1062	545	**-37%**
Textile and leather	373	338	268	295	183	**-32%**	293	181	**-32%**
Equipment goods	1363	1392	1106	1234	799	**-28%**	1232	796	**-28%**
Other sectors	672	626	491	553	331	**-33%**	552	329	**-33%**
Industry	14012	12704	9797	11174	6439	**-34%**	11185	6464	**-34%**

Source: ISIndustry calculations

Table 8-5: Comparison of final energy consumption between scenarios [PJ]

Country or country group	Reference Case			2°C Scenario (450ppm)			2°C Scenario (400ppm)		
	2005	2020	2050	2020	2050	Diff.	2020	2050	Diff.
EU27	14012	12704	9797	11174	6439	**-34%**	11185	6464	**-34%**
North	1556	1531	1488	1323	956	**-36%**	1322	958	**-36%**
South	7019	5933	4509	5211	2907	**-36%**	5217	2919	**-35%**
East	1575	1482	1247	1300	826	**-34%**	1300	831	**-33%**
West	4152	4058	2904	3603	1974	**-32%**	3610	1981	**-32%**

Source: ISIndustry calculations

Table 8-6: Additional annual investments compared to the Reference scenario [million euros 2000]

Country or country group	2°C Scenario (450ppm)				2°C Scenario (400ppm)			
	2020	2030	2040	2050	2020	2030	2040	2050
EU27	4734	6114	10970	14766	10575	9214	16787	17410
North	1012	1508	2273	3168	1656	1917	2849	3544
South	2338	2975	5349	7407	5499	4455	8420	8847
East	475	618	1253	1686	1294	1212	1999	2107
West	1318	1698	3266	4401	2615	2378	4743	4865

Source: ISIndustry calculations

Comparing the CO_2 reduction efforts among countries in Figure 8-17 reveals a variation by country close to the EU average of 33%. For the 400 ppm scenario, additional CO_2 reductions of about 7 percent vary strongly by country, depending on the use of low-temperature heat in industry because the additional reductions achieved in the 400 ppm scenario are mainly due to further solar thermal diffusion.

8.5 Conclusion on policies to achieve changes in industry sector

In order to achieve the CO_2 reductions calculated in the 2°C scenario, a variety of policy options is required to address the saving options available in industry. In other words, the policies need to take into account the very heterogeneous structure of industry, its technologies and subsectors. The following set of policy groups was identified to place industrial CO_2 emissions on the paths towards the calculated emission reductions.

- The EU ETS and the further tightening of its cap plays a crucial role in reducing direct emissions from energy-intensive industries, such as the iron and steel sector, cement production or the pulp and paper industry. This may require international agreements on climate change to reduce the danger of carbon leakage, or specific sectoral agreements, for example for the iron/steel and cement sectors.

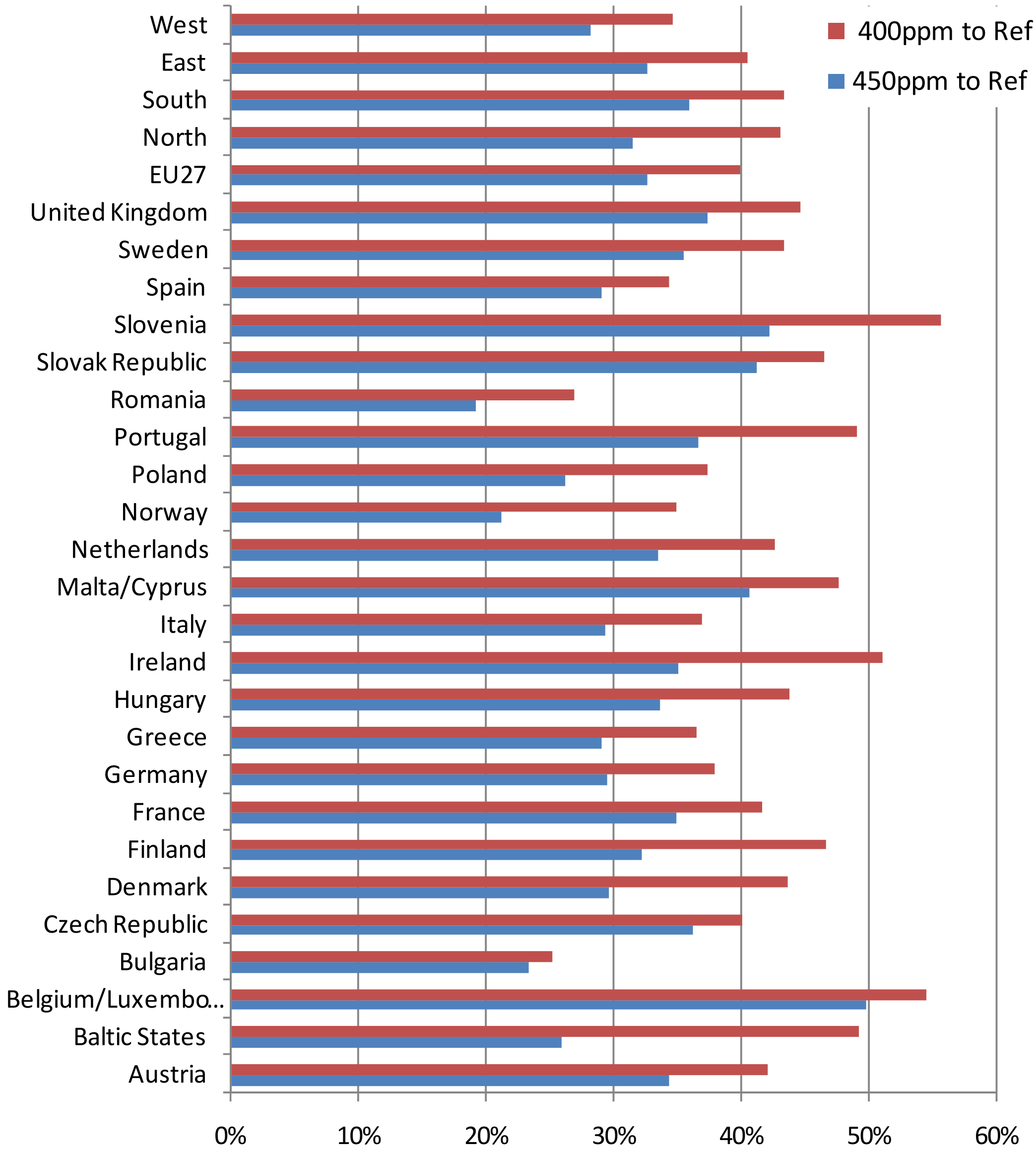

Figure 8-17: **Resulting CO_2 emission reductions in 400 and 450 ppm scenarios compared to the Reference scenario for the year 2050**

- An important group of abatement options can best be summarised as being related to the improvement of individual products or appliances with clear system boundaries, like electric motors, fans, boilers, lamps or pumps in industry. To improve the energy efficiency of these appliances, two regulatory instruments are needed. The first is the concept of minimum energy performance standards (MEPS), which sets minimum efficiency levels for products to be sold within a region or country. The second is to label even more efficient classes to enable consumers to select a product based on its energy efficiency. For both instruments, it is essential to apply policies on a European level, if not a global level. This concept is already being pursued in the EU Directives on the ecodesign of energy-using products and on the labelling of household appliances.

- Another set of saving options can be grouped under the umbrella of cross-cutting technologies (like electric motor systems, heat generation or lighting systems) and tackles system aspects more directly. Saving options in relation to these technologies are characterised first by a low degree of intervention in the production process, as they are mostly regarded as ancillary units. Second, the saving options are similar in different branches and companies so that large spillover effects could occur. Third, they have relatively large saving potentials (within a company but also economy-wide) available at low or often negative costs. These characteristics allow policies to tackle efficiency improvements across different branches (cross-cutting character) and without high subsidies or financial aid because most of the options are cost-effective. Furthermore, the barriers are relatively easy to overcome as it is not necessary to intervene in the production process. Policies that are applicable to exploit this potential include:
    - Policy options addressing the barriers to efficient cross-cutting technologies related to the fact that many electric motors are not purchased directly by the end user but rather by equipment producers or wholesalers. Such policies could, for example, include agreements with these groups to purchase more efficient motor systems, information campaigns etc.
    - Support for energy efficiency contracting. This is especially effective if the saving potentials are cost-effective and no intervention in the core production process is necessary, but the company is reluctant to invest in energy efficiency, e.g. due to budget, knowledge or capacity restrictions.
    - Further support for the implementation of comprehensive energy management systems in large companies in particular. Case studies show that comprehensive energy management systems that are implemented and monitored over a longer time horizon can reduce energy demand considerably, even if this mostly involves investing in saving options with a short payback period.
    - Energy efficiency networks, where companies work together to improve energy efficiency. These networks tend to consist of around 10 medium-sized companies that meet on a regular basis, discuss possibilities and activities to improve energy efficiency and set efficiency targets and in doing so, exchange experiences and learn from each other. The fact that the companies come from different non-competing branches allows them to work together without worrying about competitive disadvantages. Consequently, most of the realised investments in energy efficiency tackle improvements in so-called cross-cutting technologies like lighting, motor driven systems, compressed air, heat and steam generation. The

incentive for improvements in branch-specific technologies is less strong, as companies cannot learn from each other here. The success of energy efficiency networks is actually based on the assumption of available cost-effective saving potentials not being realised due to transaction costs. Experiences with a first efficiency network show that the participating companies had an annual efficiency increase which was 2 to 3 times higher than non-participating companies. In Germany, 30 additional energy efficiency networks will be launched this year, but there is still the potential for several hundreds more.

  - (Financial) Support of energy efficiency audits but also of investments in energy-efficient technologies (although the latter may be limited due to state aid considerations). The audits are conducted mostly to identify cost-effective saving potentials in cross-cutting technologies. This measure should be related to a broader energy efficiency fund that also offers financial aid for the required investments in more efficient technologies (examples are the Energy Saving Trust in the UK or the German energy efficiency fund for small and medium-sized companies). The external energy efficiency audits are especially useful in smaller SMEs, which do not have the funds available to implement a comprehensive energy management system or even participate in the above mentioned energy efficiency networks. But even in larger companies, case studies have identified larger reduction potentials for cross-cutting technologies.
  - The diffusion of information and best practices to overcome the information deficit, which is generally observed.

- In particular, the abatement options in the long term depend on the R&D activities and expenditures happening now. Although ideas and concepts to improve energy efficiency exist for the majority of industrial processes by radically changing the process involved, companies only rarely invest in R&D for such process innovations. There is also a gap when it comes to demonstration plants which require large financial inputs while still presenting high risks. There are two main explanations for these observations. The first is the long-term nature of the research process, which often lasts much longer than 10 years and is associated witha high degree of uncertainty about the payback of investments. The second is the radical character of these innovations which would make redundant the knowledge and capacity accumulated over years for the conventional process. Therefore, to foster the R&D activities on improved energy efficiency of industrial processes, public R&D spending is essential but also needs to be consistent with state aid rules. This is not only the case for process innovations, but also for emerging technologies, where R&D is also very costly, like in the field of new surface technologies and wherever large demonstration plants are needed.

- R&D could focus especially on carbon capture and storage for industrial processes. While there are alternatives to electricity generation from coal in the form of renewables, a variety of industrial processes are experiencing difficulties in further reducing their CO_2 emissions because they are operating increasingly close to theoretical limits, or because they have high emissions from process reactions which cannot be reduced unless the products are actually phased out. In the case of limited storage facilities, industrial CCS should have priority over CCS from electricity generation.
- The diffusion of efficient process innovations can be further supported by the implementation of ambitious benchmarking schemes for the most energy-intensive products (e.g. within the frame of the EU emissions trading scheme). Such benchmarking schemes would also allow the efficiency of production plants to be compared and thus increase the pressure to further improve efficiency.
- Additional financial support is crucial for the solar thermal energy, as so far these systems are associated with long payback times and high costs, especially in northern countries. Our calculations assume a stronger and quicker diffusion of solar thermal energy in the 400 ppm scenario in comparison to the 450 ppm scenario where it remains on a very low level. To achieve this fast take-off, we assumed a mixture of regulation obliging company owners to install some kind of solar system when replacing heating systems and financial subsidies depending on the specific investment costs of the system.
- Energy taxes accompanying the strong cuts in energy intensity are needed to ensure that energy efficiency improvements remain cost-effective for decision-makers in less energy-intensive companies which are not subject to the EU ETS.
- An important accompanying action to achieve the strong emission reductions, especially in the energy-intensive basic material industries, is a comprehensive material efficiency strategy that aims at reducing the consumption of these materials as well as realising the potentials for recycling. More details on the material efficiency strategy can be found in Chapter 5 on “material efficiency”.

In general, achieving the enormous emission and energy demand reductions in the 450 ppm as well as in the 400 ppm scenario will require strong policies. Most of the technological potentials available are realised in the 400 ppm scenario. Energy efficiency has to improve a lot faster than economic growth, which has not been the case in the past. Our analysis of the available technologies has showed that this is possible, but will not happen without comprehensive action.

The programme costs related to the above mentioned policies are estimated based on specific country case studies and experiences. Subsidies for comprehensive energy audits in companies would amount to about 30 million euros annually in Germany (Gruber et al. 2006).

The energy efficiency networks are estimated to cost 40,000 euros per network, with a potential of around 700 networks for Germany (Jochem et al. 2007). Subsidies for solar thermal installations are assumed to be 20% of the initial investment and a subsidy of around 5% is assumed for other energy efficiency measures in industry in the form of low tax loans for energy efficiency investments. Furthermore, for the public R&D on industrial energy efficiency, we assumed national expenditure to increase by the factor 5 (for Germany, that would mean the state providing 30 million euros instead of the 6 million it spent in 2007). CCS and other measures in the energy-intensive industries are only cost-effective due to the increasing CO_2 certificate prices. As a result, in the 400 ppm scenario, about 5% of the additional investment is from public subsidies and about 5% is also needed to develop administrative authorities. In the 450 ppm scenario, these figures are 8% and 4%, respectively. The overall relatively low share of programme costs in relation to the investments (10-12%) is due to the fact that many of the investments are driven by the CO_2 certificate price (e.g. CCS) and by MEPS (e.g. standards for electric motors), which have very low programme cost shares. To compare, other studies find, e.g. a value of 15% for supporting energy-efficient cross-cutting technologies through an energy efficiency fund (Irrek 2006).

9 Transport sector in Europe

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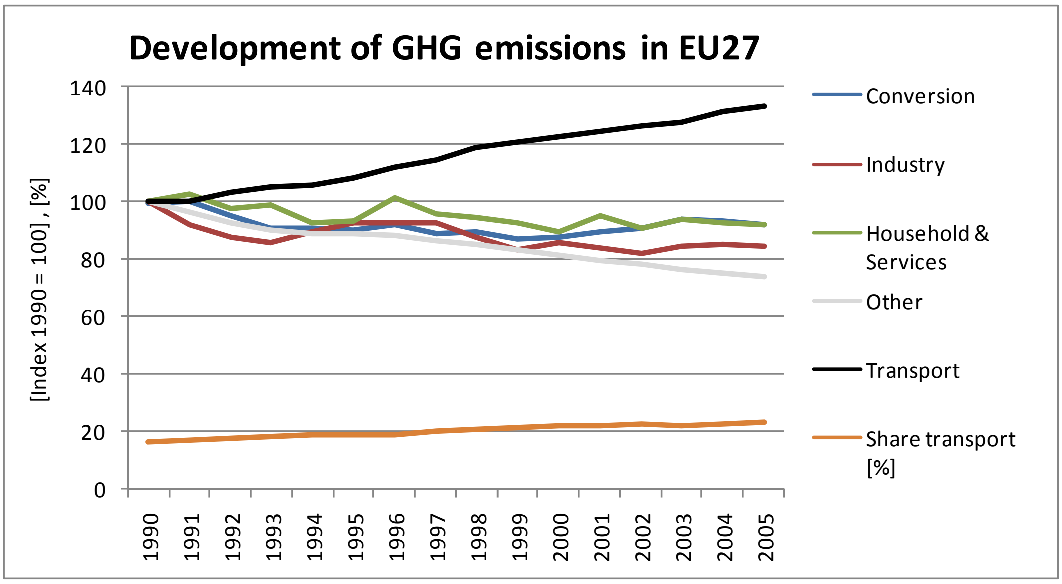
9.1 Target of analysis

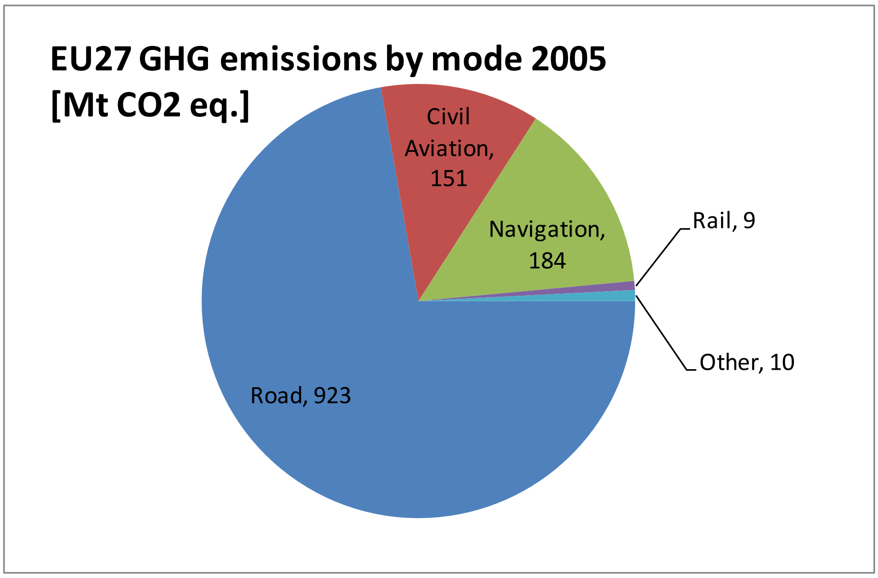
The transport sector in Europe contributed more than 23 % of EU-27 GHG emissions in 2005 (1277 Mt CO_2 eq.). Due to the high share of fossil fuel use, the share of CO_2 emissions is even higher, amounting to more than 27 % of EU-27 CO_2 emissions in 2005 (1247 Mt CO_2). As Figure 9-1 reveals, the transport sector is the only major sector in the EU-27 in which GHG emissions have risen compared with 1990. The same holds for the CO_2 emissions of transport [European Commission 2007]. Despite this growth trend, the European Commission has agreed on a target of a -10 % reduction of GHG emissions by 2020 compared with the year 2005 for the non-ETS sectors, which includes transport [European Commission 2008].



Source: European Commission, 2007

Figure 9-1: Development of GHG emissions of transport compared with other sectors in EU-27 (1990 to 2005)

The split of GHG emissions across the major modes of transport is presented in Figure 9-2. With more than 70 %, roads generate by far the largest quantity of GHG *emissions. Navigation and Civil Aviation, both including international bunkers, generated* about 14 % and 12 % in 2005, respectively.



Source: European Commission, 2007

Figure 9-2: EU-27 GHG emissions of transport by major mode in 2005

The ADAM project focuses on intra-European transport in this sector , i.e. those transport activities within European countries (EU-27 plus Norway and Switzerland) and across them. This is particularly relevant for the navigation and aviation modes. Here, intercontinental transport is excluded, i.e. transport leaving the EU to other continents or entering the EU from other continents. Pipeline transport is also excluded from the analysis.

In detail, an analysis is made of the activities of passenger and transport flows within the EU-27 plus Norway and Switzerland. The ASTRA model distinguishes five modes for passenger transport:

- Slow modes, i.e. non-motorised transport by foot and by bike.
- Car transport.
- Bus transport.
- Rail transport including trams and metros for short distances.
- Air transport (domestic and intra-EU-27+2).

For freight transport, three-plus-one modes are differentiated in the ASTRA model:

- Road mode differentiating heavy duty vehicles (HDV, larger than 3.5 t gross vehicle weight) and light duty vehicles (LDV, smaller than 3.5 t gross vehicle weight).
- Rail mode integrating inland waterways (IWW) in those countries where they play a role and allowing a separation of rail and IWW for selected indicators.
- Ship mode, which means the short sea shipping occurring within and between the European countries.

The ASTRA model enables transport emissions occurring over the whole life-cycle to be calculated but excludes those arising from vehicle scrapping. That means the emission calculations consider the emissions from the driving activity including cold start emissions, upstream emissions of fuel production and upstream emissions of vehicle production. In the ADAM project, only the emissions and energy consumption of the driving activity (the so-called hot emissions) are taken from the ASTRA model. The other types of emissions and the energy demand in the transport sector are considered in different bottom-up models, e.g. the manufacturing emissions of vehicles form part of the ISI-industry calculations. Thus the main output of the ASTRA transport model in the frame of the ADAM hybrid model system (HMS) is the transport energy demand, which is provided to the EuroMM model.

9.2 Policies, technology trends and model rationale of ASTRA

This section presents the rationale and structure of the transport model in ASTRA, which is made up of four of the nine ASTRA.[15] It is completed by the technology trends considered for the transport sector and a discussion of available policy options and the policy choice implemented in the model simulations in the 450 ppm and 400 ppm scenarios.

Major boundary conditions affecting the transport system include the growth of GDP since, so far, no decoupling has been observed (mainly relevant for freight transport), the stabilisation of the European population (mainly relevant for passenger transport), the continuous increase of fossil fuel prices due to their growing scarcity and the continued urbanisation process in Europe meaning that more people will live in urban areas compared with today which are better served by public transport, car-sharing or bicycles than by private cars.

9.2.1 Model rationale of the ASTRA transport model

In ASTRA, the spatial representation consists of 76 zones. Each of the larger EU15 countries is spatially divided into four zones (apart from Denmark and Ireland with three zones), while Eastern European countries in particular have only one or two zones. ASTRA estimates the transport demand within each zone and across all zones for five different distance categories for passenger transport and four distance categories for freight transport. The ASTRA transport model consists of four models that are embedded into the socio-economic framework provided by the economic models of ASTRA. The four transport models are:

- Transport infrastructure model (INF module).
- Passenger transport model (REM and TRA module).
- Freight transport model (REM and TRA module).

15 A detailed description of the ASTRA model can be found in [Schade 2005].

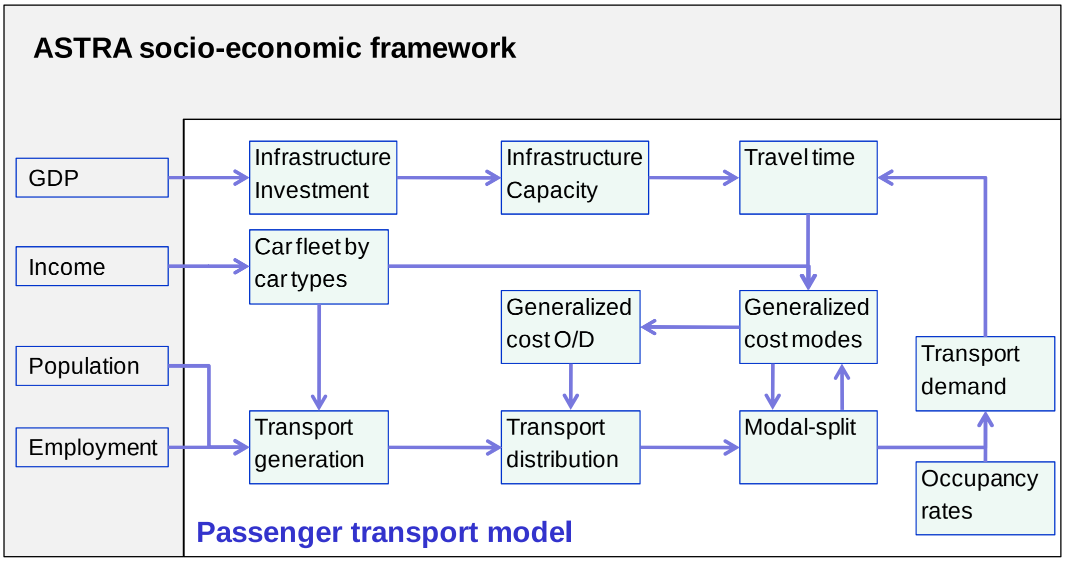
- Vehicle fleet model (VFT module).

Transport infrastructure in the infrastructure model is driven by the investment in infrastructure that in turn depends on (1) GDP development, and (2) policy choices about which types of infrastructure should be financed, e.g. the Trans-European-Transport-Networks (TEN-T), rail freight corridors, ports etc. The capacity of infrastructure then influences the travel times and thus the destination and mode choices in the passenger and freight transport model.

Figure 9-3 presents the major interdependencies of the passenger transport model. The main output of the model is the passenger transport performance by mode as well as the vehicle-kilometres-travelled (VKT) by mode. The core of the model is a classical four-stage transport model [see Ortuzar/Willumsen 2004] with a rather limited assignment component (4^{th} stage). However, the first three stages act in an integrated and dynamic way, i.e. at none of these stages (generation, distribution, mode choice) are any assumptions made about structural stability. In the generation stage, e.g. changes in population, degree of (un-)employment or the car fleet may alter the number of generated trips. In the distribution stage, of course, changes may stem from generation, but more important is the **aggregated generalised transport cost** between any origin (O) and destination (D) in Europe. These aggregated costs consist of monetary costs and time costs and thus represent an accessibility measure for each European OD-relation described by the ASTRA functional zoning system.

Accessibility is influenced by the travel time (depending on infrastructure and network load) and the travel cost (depending, e.g. on tariffs, car prices, fuel prices, car taxes etc.) by mode. The same influences also affect the mode choice for each OD relation and each distance band (0-3.2 km, 3.2-8km, 8-40km, 40-160km, >160km distance). As a starting point for travel distances and travel times for each OD relation, the input from a European network model (in ADAM this is still the SCENES model [ME&P 2000]) is integrated into ASTRA. Distances and travel times change due to exogenous (e.g. growth of average distances within distance bands) and endogenous influences (e.g. investment in infrastructure, destination choice shifts to further away destination zones).

In the final step, passenger transport performances by mode are converted into vehicle kilometres using distance- and mode-specific occupancy rates. The occupancy rates are taken from national travel surveys (e.g. UK national travel survey) and decrease over time. The major outputs of the passenger transport model comprise the energy demand, emissions, transport expenditures, transport tax and toll revenues.

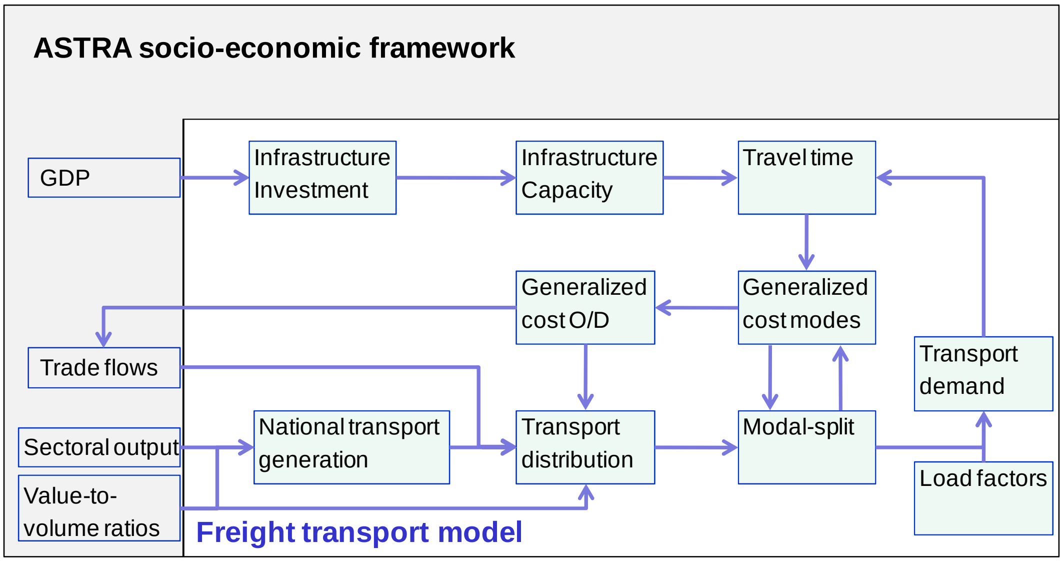


Source: Fraunhofer-ISI, own presentation

Figure 9-3: ASTRA passenger transport model

Figure 9-4 shows the major interdependencies of the freight transport model. The main outputs of the model are the freight transport performance by mode as well as the vehicle-kilometres-travelled (VKT) by mode. The basic structure of the freight transport model is similar to that of passenger transport; it is a classical four stage transport model including only a limited 4th stage for assignment. A major difference concerns the distribution model of international freight transport, which derives the freight flows for the OD relations based on foreign trade flows. National transport flows are derived from the sectoral output of each goods producing sector (15 sectors) in the 29 European countries.

In the final step, freight transport performances by mode are converted into vehicle kilometres using distance- and mode-specific load factors. The load factors are taken from the SCENES model and exogenously increase over time due to the assumption of improved logistics. Further, the load factors are endogenously altered by transport cost, e.g.. to reflect organisational improvements in response to higher fuel prices or fuel taxes. The major outputs of the freight transport model comprise the energy demand, emissions, investments in freight vehicle fleets, transport tax revenues and toll revenues.



Source: Fraunhofer-ISI, own presentation

Figure 9-4: ASTRA freight transport model

A third model relevant for the ADAM project is the car fleet model consisting of a stock model, a purchase model and a choice model for the selection of newly purchased cars. The car fleet model constitutes one of the most policy-sensitive model elements in ASTRA as it reacts to policies that support new technologies (e.g. subsidies or 'feebates', a novel combination of fees and rebates), to taxation policies (i.e. car and fuels) and to fuel price changes including changes of CO_2 taxes/certificates and energy tax changes. Other socio-economic drivers also affect the development of the car fleet, especially income, population and the existing level of car-ownership.

The car fleet model starts with the purchase model, which determines changes in the absolute level of the car fleet. Depending on changes in income, population and fuel prices, the level of the car fleet is estimated for the next time period. Together with information on the scrappage of cars which mainly depends on the age structure of the fleet, the number of newly purchased cars is then calculated. Purchase of cars via the second-hand market from other countries is neglected, which is a simplification that played a role for the new Member States before they joined the EU.

In the second step, the newly purchased cars are transmitted to the choice model, which determines the types of cars that are purchased. Car types include:

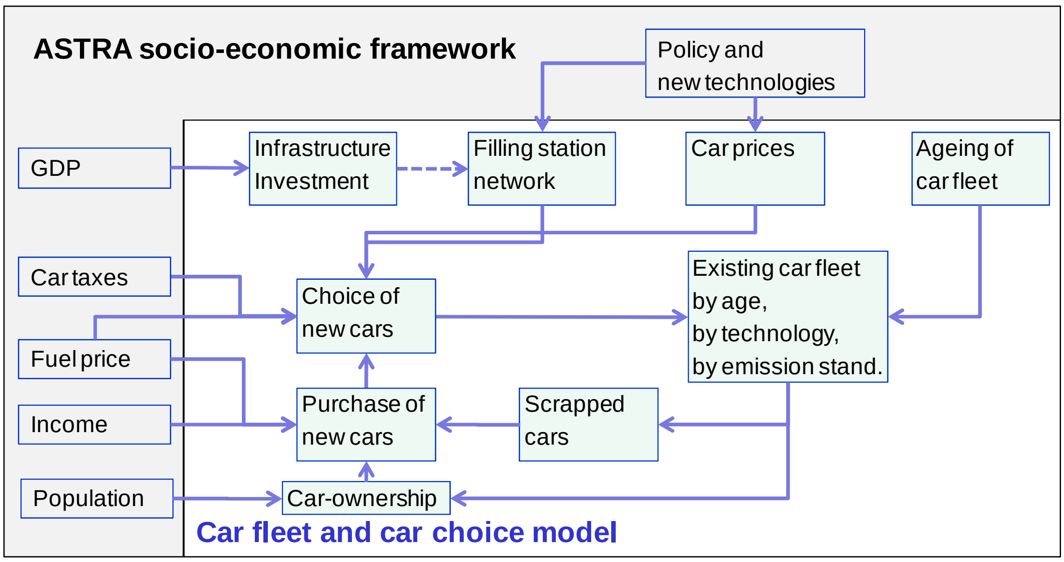
- Gasoline cars: three types differentiated by cubic capacity (<1.4l, 1.4-2.0l, >2.0l),
- Diesel cars: two types differentiated by cubic capacity (<2.0l, >2.0l),
- Compressed natural gas (CNG) cars,
- Liquefied petroleum gas (LPG) cars,

- Bioethanol cars, i.e. cars that can run on 85 % bioethanol (E85) and more (incl. flex fuel),
- Hybrid cars, meaning advanced hybrid cars depending on timing, i.e. plug-in hybrids with the ability to run for a significant distance on electricity,
- Battery electric cars, i.e. smaller cars running in battery-only mode,
- Hydrogen fuel cell vehicles (hydrogen internal combustion engine is not considered a reasonable option).

The choice of new car depends on fuel prices (incl. taxes), car prices, taxation of car technologies, efficiency of cars, filling station network and, in the case of new technologies, on subsidies or feebates (combined fee and rebate system). In the case of electric vehicles, preferences are also altered by adapting the choice parameters in the model equations.

Emission standards are also considered in the car fleet model. The point of time when a new car is purchased determines to which emission standard it belongs and which emission factors have to be applied to model its emissions. ASTRA distinguishes nine emission standards (2 pre-euro standards, euro1 to euro 7 standard). For example, if a car is purchased in 2005, it is assumed that it complies with the euro 3 standard.

The third element is the stock model of the existing fleet. This model provides the number of cars and the age distribution in the fleet . Using age-specific scrappage functions and a cohort approach, the model simulates ageing of the individual cohorts of the fleet. Thus it is feasible to analyse at any point of time the number of cars using a certain engine technology and belonging to a certain emission standard.



Source: Fraunhofer-ISI, own presentation

Figure 9-5: ASTRA car fleet and car choice model

The major function applied in most of the transport models are discrete choice functions, i.e. logit functions [Ortuzar/Willumsen 2004]. These are, for instance, used to model the destination choice, mode choice and car purchase choice. The following two equations illustrate the mode choice calculation for passenger transport resulting in the transport demand by mode and trip purpose for a specific origin-destination pair:

$$D_{m,TP,OD} = D_{TP,OD} * \frac{e^{-\lambda_{m,TP} * GC_{m,TP,OD} + MC_{m,TP}}}{\sum_m e^{-\lambda_{m,TP} * GC_{m,TP,OD} + MC_{m,TP}}} \qquad \text{(eq. 9-1:)}$$

$$GC_{m,TP,OD} = DIST_{m,OD} * C_{m,TP} + DIST_{m,OD} * SP_{m,TP,OD} * VoT_{TP} \qquad \text{(eq. 9-2:)}$$

Where: D = transport demand (by purpose and origin destination (OD) pair) [trips]).

GC = generalised cost [€].

λ = logit parameter defining the elasticity of the modal shift [1/€].

MC = modal constant.

DIST = distance between origin and destination of trip [km].

C = specific cost per km by mode and trip purpose [€/km].

SP = speed of mode [h/km].

VoT = value-of-time [€/h].

m = index for modes (i.e. car, bus, rail, air, slow).

TP = index for trip purposes (business, private, tourism).

OD = index for origin and destination zones i.e. OD-matrix.

For clarity reasons, the index for European countries has been omitted. In the ASTRA model, all these equations would additionally include a country index representing the 28 European countries modelled in ASTRA. Instead of the GC-term (generalised cost), the equivalent logit equation for the car purchase choice would have a term that describes the utility parameters of cars, e.g. the vehicle price, fuel price, fuel efficiency, fuelling station network and vehicle taxation.

9.2.2 Transport technology trends

Though the internal combustion engine has been the dominant propulsion technology in the transport system for about one hundred years, it cannot be expected that this will continue in the next decades as well. The growing scarcity of fossil fuel resources, the challenges of combating climate change and the availability and competitiveness of new technologies will lead to a diversity of fuels and engine technologies in transport over the next 40 years.

Backed-up by corresponding cost developments of vehicles and fuels in the ASTRA model, the following specific trends are expected to play a significant role in the mitigation scenarios:

- Conventional cars with internal combustion engines still have high energy efficiency potentials. The efficiency potentials for gasoline are higher than those for diesel cars in the future [TNO 2006].
- The breakthrough in battery technology (in particular in lithium-ion batteries) will enable battery electric city cars to gain large market shares in short and medium distance car transport.
- Electric engines and batteries will also be available for light duty vehicles used for last-mile delivery in cities.
- It will not be possible to replace the internal combustion engines in heavy duty vehicles and air transport with alternative engines in the next 40 years. Thus besides efficiency improvements, the main option to reduce the GHG emissions of these modes is to switch to higher shares of second (third) generation biofuels.
- CNG starts to play a role as a low carbon fossil alternative to gasoline and diesel for cars, buses and trucks as well as a bridge technology towards hydrogen for transport.
- After 2030 hydrogen fuel cell vehicles also begin to enter the market, but their share remains limited as long as fossil fuels are still available and renewable energy production is limited.
- For maritime shipping, the use of wind power (e.g. sky sails, turbo sails, Flettner rotors) will start to play a role due to growing fossil fuel and CO_2 prices. This was not considered for the short sea shipping in the ASTRA model, which underestimates the potentials of these technologies.

9.2.3 Policy options for passenger cars

In this section, a number of car fleet related policies are explained in more detail to demonstrate important fiscal policies and information measures which are being discussed and which aim to transform the transport system into a low carbon emitting system. The measures concentrate on those that would change car purchase behaviour (energy / CO_2 labelling, a CO_2 based circulation tax and feebates on new passenger vehicles). Findings in the literature on their effects are described to derive the assumptions about the CO_2 reductions induced by these measures implemented in the ASTRA model.

9.2.3.1 Energy / CO_2 labelling of new passenger vehicles

Energy/ CO_2 labelling is an information tool. In Europe, a label similar to the one used for household appliances (showing seven colour-coded bars for the efficiency classes A (very efficient) to G (very inefficient)) is being used or considered by several countries [de Haan et al. 2009]. However, countries vary markedly in how they classify vehicles. If they define energy efficiency in an "absolute" way, the rated CO_2 emissions directly determine the efficiency class of a vehicle. An alternative policy base results from the notion of "relative" energy efficiency, which is computed by normalizing energy consumption to car size operationalized by, e.g. floor space, curb weight or car length. The specific design of a labelling scheme might be important for its effects, especially when other measures such as vehicle taxation are directly linked to its categories. A study of Peters et al. [2008] suggests that a relative system succeeds better in addressing more consumers. However, a relative system potentially allows people to switch to cars with higher relative efficiency without actually lowering absolute CO_2 emissions. Here, it is important to find the optimal trade-off.

In the literature, a few studies have been made on the impact of labelling on the energy efficiency and CO_2 emissions of new vehicles. However, their results vary with the methods used. Based on a survey in Austria, E.V.A. et al. [1999] studied the impact of labelling on the consumer's car purchase decision and came to a rather optimistic estimation of the possible effect. They concluded that, on average, 4-5 % lower specific fuel consumption and CO_2 emissions of newly registered cars could be obtained.

In a Swiss study, Iten et al. [2005] analysed the impact of the Swiss energy label, which was introduced in 2003. Amongst others, they conducted a discrete choice analysis of Swiss consumers to study the effect of the label on car choice. Based on the results and following market simulations, they estimated that the energy label could reduce the specific fuel consumption of the car fleet by 0.4 % per year. However, the discrete choice analysis included some flaws, e.g. unrealistic combinations of vehicle characteristics.

In a cross-national study by the ADAC [2005] on the effectiveness of the EU car labelling Directive (which was adopted in December 1999), there was no evidence that labelling had contributed to a reduction of the average CO_2 emissions of new cars sold in the EU. The study was based on an evaluation of the Member States' reports, findings of other studies, the results of a survey of European automobile club members and an analysis of data on the average specific CO_2 emissions of new cars. The authors point out that, due to the different elements of the European strategy and continuous technical improvements, it is very difficult to attribute a shift in purchasing behaviour to such an information tool. Despite this conclusion, they still consider the labelling scheme a useful tool for raising awareness about the climate change impacts of passenger cars. But more time is needed for the Directive's provisions to achieve their full effect. Moreover, as labels varied strongly in their quality among EU Member States, a common and improved EU labelling scheme should be developed. The inclusion of an energy efficiency rating system is especially recommended to allow consumers to compare vehicles more easily.

In general, to be effective, such a label should be used as part of a package of measures, rather than as an isolated measure. For example, labelling can be an important way to raise consumer awareness about the impact of car use on CO_2 emissions and climate change if vehicle taxation is linked to its categories and can then result in significant medium- to long-term indirect impacts on car purchasing behaviour.

For calculating the CO_2 reductions induced by energy/ CO_2 labelling of new passenger vehicles within the ASTRA model, we assumed that labelling can have a moderate impact on the car purchasing decision and increases the probability that consumers will choose more efficient vehicles if it is developed and designed effectively and accompanied by broad information campaigns. Such a moderate estimation of the resulting effect on energy efficiency and CO_2 emissions might range around 3 % reduction considering that, in a mitigation scenario, fuel efficient cars are on the market and that the level of awareness is significantly higher than in the Reference Scenario.

9.2.3.2 CO_2 based annual vehicle circulation tax

The specific design of the annual vehicle circulation tax differs substantially among EU Member States with regard to the level of taxation, the extent to which differentiation is applied and the tax base (e.g. kW, cylinder capacity, weight of the car) [Kalinowska et al. 2005; Kunert/Kuhfeld 2007]. Linking the annual circulation tax (ACT) to the CO_2 emissions of a vehicle throughout the EU might be an effective measure to reduce the energy consumption and CO_2 emissions of road transport.

The UK already introduced CO_2 emissions as the explicit ACT base in 2001. This CO_2-based tax scheme was studied by Lehman et al. [2003] via interviews with new car purchasers who had bought a car under the new tax scheme or who were planning to buy a new car within the following year. Under the new tax scheme, the difference between the bands was around €15-45, ranging from €83 ACT for an alternative fuel car with CO_2 emissions of up to 100g/km to €248 ACT for a diesel car with CO_2 emissions over 185 g/km. The results indicate that the current graduated scheme does not offer a large enough incentive to change purchasing behaviour, but that increased differentiation would enhance the scheme's effectiveness. According to the authors, a differential of €75 between bands would be enough for at least 33 % of buyers to choose a different car. At a differential of €225, more than half of the interviewed buyers would change to a lower emission car in order to benefit from the saving. However, 28 % of respondents, typically older respondents of a higher social class who already own or intend to buy a vehicle with a larger sized engine, would not change their vehicle choice regardless of the differential. In general, the study points out the importance of effective information measures. At the time the study was conducted, the message that the ACT in the UK was linked to CO_2 emissions had not reached many private car buyers.

For Ireland, which changed its vehicle tax policy in July 2008 and introduced a CO_2-based ACT as well as a CO_2-based vehicle registration tax (VRT), Giblin and McNabola [2009] predicted the impacts of these changes. For the ACT, they estimate a 2.2-2.4 % reduction in the average CO_2 emissions from new cars. The authors also proposed changes to both the ACT and the VRT which would optimise both reductions in CO_2 emissions and reduce losses in tax revenue. To do so, the ACT rates of Ireland would have to be increased by 15-25 %.

In a cross-national study, COWI [2002] estimated the potential of restructured ACT systems based on CO_2 emissions for nine European countries using scenario simulations. The estimated CO_2 reductions in the individual Member States range around -4.5 % compared to existing systems based on horsepower. The estimated effects depend on the conditions in the individual countries and are affected, e.g. by the existing tax systems and the market composition. The biggest effect was estimated for the Netherlands with 6 % and the smallest one for Portugal with 2.3 %.

The results of the above mentioned studies underline that the efficacy of CO_2-based taxes depends on their specific design, e.g. the tax level and differentiation between vehicles, as well as on the provision of effective information to consumers about the tax basis and aims.

More tips for the specific design of tax schemes are provided by studies made in the US which indicate that consumers only consider the first 2.8 to 3 years, or only the first 50,000 miles when assessing the value of higher energy efficiency [cf. Greene et al. 2005]. This suggests that financial incentives in the first three years are relevant for consumers, but later incentives probably not. Thus, another effective design might be to exempt consumers of very energy-efficient new vehicles from the ACT for three years instead of levying the same tax across the whole ownership period.

However, interviews with car buyers suggest that consumers do not use payback periods, but calculate the financial aspects of energy efficiency only very roughly, if at all [e.g. Kurani 1992; Kurani/Sperling 1988; Turrentine/Kurani 2007]. In fact, other aspects of energy efficiency may be more important to consumers such as technology, environmental aspects or the strong symbolic image of energy-efficient vehicles. Nevertheless, financial incentives of a relevant level can raise awareness of these issues, especially when accompanied by information campaigns [de Haan et al. 2007].

For calculating the CO_2 reductions induced by a CO_2-based ACT within the ASTRA model, we assume a reduction effect of about -4.5 % at the time of introduction provided that consumers are effectively informed about the measure. However, unlike a tax levied at the time of purchase, of which consumers are always very conscious, the awareness of the link between the ACT and CO_2 emissions may subside over time and thus also its effect on consumer behaviour. Hence, we assume a moderate decrease by 1 % until 2015. This measure was treated as an additional option to enforce the transport policy on cars, but it was not implemented in the 2°C scenarios.

9.2.3.3 Feebates on new passenger vehicles

In order to promote very energy-efficient vehicles such as the upcoming electric or fuel-cell vehicles, feebates might be a feasible tool. Feebate systems combine rebates for very energy-efficient vehicles with additional fees for very inefficient vehicles [de Haan et al. 2009]. Various possible types of feebate schemes and design options appear in the literature [DeCicco et al. 1993; Greene et al. 2005; HLB Decision Economics Inc. 1999; Johnson 2006; Peters et al. 2008; Train et al. 1997].

A study of Iten et al. [2005] indicates that the implementation of a feebate system (here: rebates funded by a general increase of the VRT) based on the Swiss energy label would enhance the impact of such a label. Assuming a rebate of €1200 for ‘A’ labelled vehicles and of €800 for ‘B’ labelled vehicles funded by an increased purchase tax, they estimated that the specific fuel consumption of the new car fleet could be reduced by -1.6 %.

In another Swiss study based on simulations, de Haan et al. [2009] assumed incentives of €2000 only for ‘A’ labelled cars (again funded by an increase of the VRT) and concluded that they would induce CO_2 emissions reductions of between 3.4 and 4.3 % for new car registrations.

A study of Giblin and McNabola [2009] analysed the effects of the Irish CO_2-based VRT introduced in July 2008 and estimated a resulting reduction of 1.6-1.7 % in CO_2 emissions. For the combined effect of the restructured ACT and VRT, a 3.6-3.8 % reduction was calculated (estimated reduction for ACT alone presented above). Proposed changes to both the ACT and the VRT could result in an improved reduction of 5.1-5.7 %.

In the study of COWI [2002], the reduction potential of CO_2-based VRT systems across selected European countries was estimated to range between 1.8 % (for Italy) and 8.4 % (for Denmark). Combining CO_2-differentiated VRT and ACT results in reductions ranging from 4.3 % (for Finland) and 8.5 % (for Denmark).

It should be noted that the above mentioned studies only considered the effects of car choice models on consumers . In a small country without large car manufacturers, manufacturers might not be encouraged by a national feebate system to adopt more vehicle efficiency technologies [Langer 2005]. However, if feebates are introduced in large countries that represent a relevant share of the vehicle market or at EU level, studies modelling feebates on a broader level which also consider manufacturer’s behaviour predict quite large effects (over 20 % reduction in average CO_2 emissions) which are mainly due to the manufacturers’ response [e.g. Davis et al. 1995; Greene et al. 2005].

De Haan et al. [2007] pointed out that traditional methods to forecast the effects of feebates are based on oversimplifying assumptions and do not capture all the relevant elements of consumer and manufacturer behaviour. For both consumers and manufacturers, they are limited to the monetary effects of feebates [Langer 2005]. However, on the consumer side, other mechanisms which affect important psychological factors influencing car purchase behaviour are also relevant, such as norms, values, the image of energy-efficient vehicles and the perceived opportunity to do something about the problems linked to fuel consumption. These mechanisms have the potential to address consumer segments with lower price elasticity in contrast to the sole monetary component of feebates. Thus, de Haan et al. [2007] assume that such models underestimate the effect of feebates on consumer behaviour. However, in order to exploit the full potential of feebates, effective accompanying information and marketing measures are decisive. Moreover, a combination of feebates with a regulatory program (e.g. CO_2 emissions standards) might be a feasible approach to reduce vehicle emissions faster, as feebates could shift the market towards the efficient vehicles which have to be sold by manufacturers in order to meet the standards [Langer, 2005].

Of course, the specific design of the feebate system is decisive for the effect of specific fees or rebates. As mentioned above, feebates based on a relative definition of energy efficiency might have more success in addressing greater numbers of consumers but, at the same time, they potentially allow people to switch to cars with a higher relative efficiency without actually lowering absolute CO_2 emissions. Here, it is important to find the optimal trade-off (see discussion in Section 9.2.3.2). With regard to the handling of payments, according to de Haan et al. [2007], rebates and fees should be paid and charged separately instead of being charged directly against the purchase price, as the perceived value of separate payments is higher.

As consumers are reminded of this tax at the time of the purchase in contrast to an annual circulation tax linked to vehicle characteristics, we do not assume that this effect will diminish over time as long as this measure is implemented. Moreover, it can be expected that its effect on consumers will endure even if feebates are only implemented for a certain time frame, if their potential to change consumer awareness, norms and values is used. However, for manufacturers, stable instruments which represent and follow long-term political objectives seem to be important to create enduring effects.

Based on this outline, we assume a CO_2 reduction of 5 % induced by effectively designed feebate systems. We did not implement the feebate system fully as a separate measure on its own, but assumed that a moderate system would support the labelling and CO_2 regulation measures for cars.

Subsidies for alternative fuel vehicles and fuelling infrastructure:

As mentioned above, feebates on new passenger vehicles, in particular rebates for very efficient ones can also be effective in promoting the diffusion of alternative fuel vehicles, such as battery-electric vehicles or fuel cell vehicles, which require a special fuelling/charging infrastructure. As their diffusion shows specific characteristics and requirements, in the following, we present some conclusions which can be drawn based on the experiences with the introduction of natural gas vehicles (NGVs) in various countries.

Based on data on the adoption of NGVs in eight countries (Argentina, Brazil, China, India, Italy, New Zealand, Pakistan, and the US.), Yeh [2007] examined a range of factors that influence the adoption of NGVs. Several economic factors, such as the purchase costs of NGVs, the natural gas fuel price, the profitability of operating refuelling stations, and selling/installing vehicle equipment, can affect consumer and investor decisions to enter the NGV market. Janssen et al. [2006] also point out that the price for natural gas should leave enough room for an attractive margin for fuelling station investors and for customers buying NGVs. In countries where the price difference to gasoline and diesel is too low, fuel tax reductions and subsidies for fuelling stations could compensate this unfavourable condition. Yeh [2007] concludes that natural gas fuel prices of 40–50 % below gasoline and diesel prices and incentives to keep the payback period at 3–4 years or less are important keys for a widespread adoption of NGVs.

With regard to the vehicle-to-refuelling-stations ratio, countries with a large number of NGVs show a ratio of 1000 vehicles per refuelling station [Janssen et al. 2006; Yeh 2007], which seems to be the optimal balance between profitability for fuelling stations and consumer convenience and thus very decisive for market development. This ratio could be a useful indicator to monitor the effectiveness of government policies and make policy adjustments based on its values, either to promote vehicle adoption or to stimulate the installation of refuelling stations. With regard to Germany, Janssen et al. [2006] point out that in 2003, Germany showed a high ratio of fuel stations to gas cars with a quickly growing fuelling station infrastructure of approximately 250 public fuelling stations (+150 non-public), whereas the current 18,000 NGVs only show a moderate growth rate. This may have been a major barrier to the diffusion of NGVs in Germany.

Moreover, the availability and reliability of vehicle technology and components are important factors for consumer acceptance of NGVs and alternative fuel vehicles in general [Yeh 2007]. Struben and Sterman [2008] point out that consumer willingness to consider a vehicle type is important for the adoption of AFVs and that this can be generated by marketing and media, direct social exposure to the vehicle type and word of mouth. For the self-sustaining adoption of AFVs by consumers, awareness and adoption must exceed a certain tipping point.

The critical ratios and required infrastructure may vary according to the specific type of alternative vehicle (e.g. plug-in-hybrid vehicle, battery-electric vehicle; fuel cell vehicle), its capacities with regard to range and fuelling/charging capacity and driver behaviour. Here, more research is needed on the conditions for successful diffusion and use. But in general, policies such as subsidies for alternative vehicles, e.g. within a feebate system, and fuelling infrastructure are required for the successful diffusion of AFVs that persist over periods long enough to reach the critical tipping points [cf. Struben/Sterman 2008]. As a result, a feebate system was considered to be implemented during the initial market entry period of battery electric vehicles and hydrogen fuel cell vehicles.

9.2.4 Policy choices for transport in the EU

To simulate the mitigation scenarios in the ASTRA model it was necessary (1) to take into account the cross-cutting policies relevant for all sectors, and (2) to make a selection of the available transport policies, some of which were discussed above. The main cross-cutting policy considered for transport is the existence of a CO_2 certificate system, which would be the EU-ETS to start with that is extended in the post-Kyoto period to a global ETS system. Rail transport is subject to the EU-ETS from the beginning as far as electric rail transport is concerned. Air transport and ship transport become part of the ETS around 2012 and the remaining road transport is integrated into the ETS via an upstream system around 2020. However, strong impacts of an ETS should not be expected for road transport in particular as even at prices of 100 €/t CO_2, the price increase of one litre gasoline fuel would be around 26 cent/l, which will only have limited impacts, if this is not accompanied by other measures. On the other hand, including road transport is important to obtain a closed system, i.e. one covering all the major sources of emissions, in order to be able to calculate the cap on CO_2 and GHG emissions. As including transport in the ETS via an upstream approach has the same effect as increasing the fuel tax, no further fuel taxation policy was considered.

Table 9-1 presents the transport policies that have been selected to simulate the ADAM mitigation scenarios. The selection is based on the heuristics of the feasibility, technical availability and comparative cost of the measures, but not on an optimised cost competitiveness. This seems a better course to pursue given the uncertainties of scenarios that run 40 years into the future.

Broadly speaking, the 450 ppm scenario can be characterised as focusing on passenger transport, urban freight transport, new engine technologies (in particular electric city vehicles and hydrogen fuel cells) and biofuels. The 400 ppm scenario adds measures for long-distance freight transport, in particular the efficiency of HDV, improved logistics, improved competitiveness of railways and a modal shift to rail freight. Air transport in both scenarios is mainly addressed by the introduction of biofuels and the impact of including it in the ETS, which has a dampening impact on air transport growth in the longer run when CO_2 prices reach levels of 50 to 100 €/tCO_2.

It is also assumed that the European policy to improve the competitiveness of rail transport for both passengers and freight is continued and even augmented. In terms of passenger transport, this means the continued expansion of the high-speed rail network, upgrading speed restricted sections to standard speeds and the consistent introduction of synchronised timetables all of which increase the reliability and frequency of rail transport.

In terms of rail freight transport, this means eliminating bottlenecks, i.e. building dedicated freight rail tracks for sections or nodes that are relevant for long-distance rail freight but that face capacity constraints. In addition, cooperative logistics, i.e. logistic planning across different forwarding companies, should be fostered such that sufficient freight demand is generated to load full trains for long-distance shipments. Since such improvements also require infrastructure investments, these should be funded by revenues from the ETS payments of transport.

Table 9-1: Transport policies in the ADAM scenarios

Area	450 ppm scenario	400 ppm scenario
Cross-cutting policy		
Inclusion in ETS (air/ship 2012, road 2020)	Path to 80€/t in 2050	Path to 198€/t in 2050
Car transport		
CO_2 emission limits for cars	Up to -10 % fuel efficiency compared with REF	The same
Efficiency labelling of cars	Avg. -3 % energy demand	The same
Low resistance lubricants binding legislation	-2.5 % energy demand	The same
Battery technology breakthrough (E-mobility), policy support and linkage of battery vehicles with increased use of renewable electricity	City cars only, diffusion by R&D&prototype-sup-port 2010, market share 3 % in 2020, 8 % in 2050	Additional feebate for market entry, market share 8 % in 2020, 21 % in 2050
Hydrogen fuel cell breakthrough, policy support for R&D, field tests and subsidies at market entry. Fuelling station network build-up.	Market entry 2025, market share 1 % in 2030, 8 % in 2050	The same
Bioethanol quota (partly by blending in gasoline)	10 % of gasoline in 2020 (flex fuel cars & blended)	Quota increase to 20 % in 2035, 25 % in 2050
Rail passenger transport		
Increased competitiveness compared with long distance road and air transport	---	Rail infrastructure and services improved
LDV transport		
Battery technology breakthrough (E-mobility)	Starting 2015, reaching 10 % new LDV in 2030, and 30 % in 2050	The same
CO_2 emission limits for LDV enforced early	Up to -10 % fuel efficiency compared with REF starting 2016, fully effective 2024	The same
CO_2 emission limits for LDV medium-term enforcement	---	Up to -10 % fuel efficiency compared with 450ppm starting 2025, fully effective 2040
HDV transport		
CO_2 emission limits for HDV in medium-term	---	Starting 2030, reducing CO_2 -5 % by 2040 and -10 % by 2050.
Additional reaction of logistics to cost increase of CO_2 certificates	---	+15 % / 21 % increased load factor short/long
Driver education	---	Up to -10 % fuel efficiency relative to REF
Low resistance tyres	---	Up to -5 % fuel efficiency relative to REF
Logistics		
Improved logistics for all freight modes reduces vehicle-km	Corporate logistics, network logistics etc.	The same
Improved rail logistics, improved rail freight accessibility+information => modal-shift to rail	---	Starting 2020, +5 % rail mode share in 2050
Biofuel		
Quota for biodiesel in road transport (in REF scenario the quota is already 9 % in 2020)	Increase to 12 % in 2030 and 16 % in 2050	Increase to 17 % in 2030 and 30 % in 2050, increase mainly HDV
Quota for biodiesel in rail transport for diesel engines	Starting 2015, 5 % share in 2030, 15 % in 2050	The same
Quota for biofuel in air transport (e.g. Jatropha based)	Starting after 2012, 4 % in 2020, 10 % in 2030, 25 % in 2050	Starting after 2012, 4 % in 2020, 20 % in 2030, 50 % in 2050 (doubling)

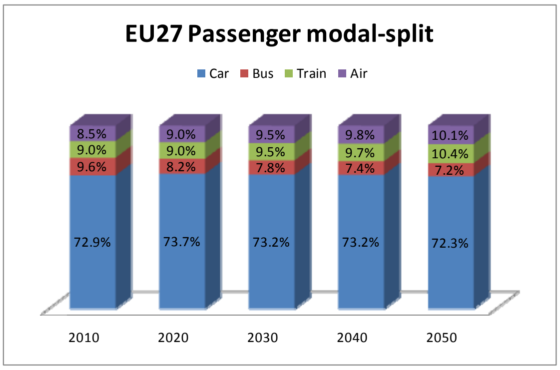
Source: Fraunhofer-ISI, ADAM project

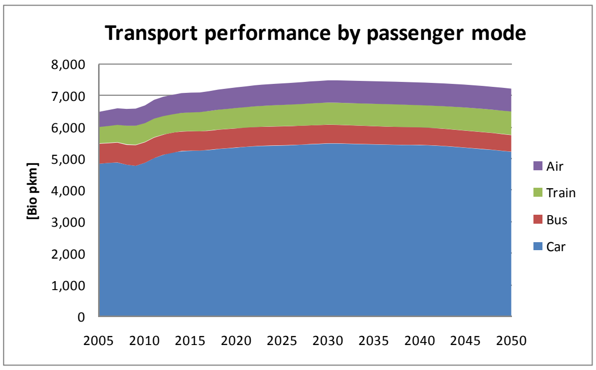
9.3 Results of scenarios

This section presents the scenario results for the transport sectors for the two variants of the ADAM 2°C scenario: the 450 ppm scenario (450 ppm) and the 400 ppm scenario (400 ppm). Since, the comparison with the Reference Scenario (REF) is often used to illustrate the results, this section starts with a brief presentation of the major transport trends in the Reference Scenario until 2050.

9.3.1 Overview of the Transport Reference Scenario

Figure 9-6 presents the trends for passenger transport. Total demand increases only slightly until about 2035 and then declines due to the demographic development in Europe, i.e. the population decrease, which actually starts more than a decade earlier. It should be noted that air transport only includes intra-European transport, i.e. excludes the fastest growing segment - intercontinental air transport. It can also be observed that road transport will remain the most important mode with a modal share of more than 70 % of all passenger-km (pkm). Air transport shows the strongest increase in modal share, but rail transport also increases its modal share due to the greater availability of high-speed rail connections in the EU. On the other hand, bus transport has a reduced modal share as a result of the demographic development (i.e. fewer children and less demand for transport to education centres), changes in transport behaviour in Eastern Europe (i.e. growing car-ownership and less use of public transport) and changed trends in the older generations (i.e. more retired persons own a car than was the case in the past).

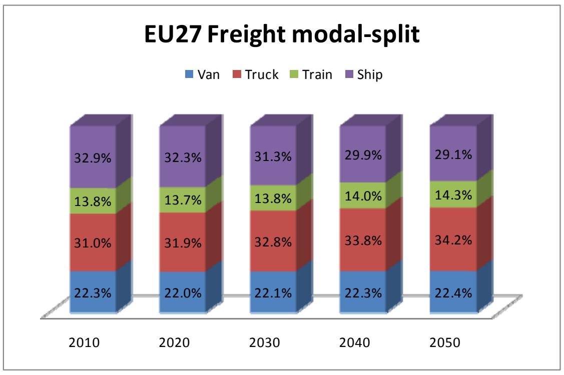


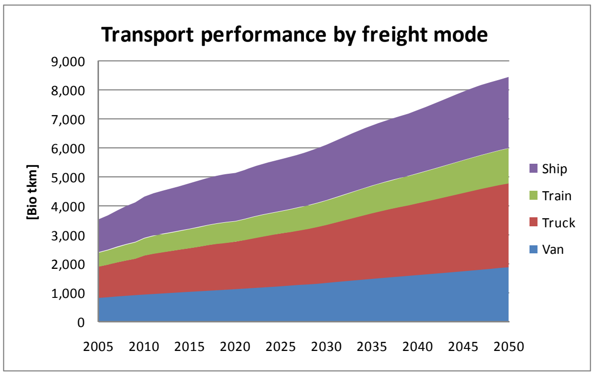


Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-6: Development and structure of passenger transport demand in EU27 (Reference Scenario)

The picture for freight transport demand differs significantly as revealed by Figure 9-7 . Total freight transport performance increases by more than 130 % from 2005 until 2050. Heavy goods vehicles show the strongest growth; their modal share increases by more than 3 %. There is also a slight increase in the modal share of rail freight[16] as a consequence of the European railway liberalisation together with the construction of an interconnected European rail network. Short sea shipping suffers a slight loss of its modal share but continues to be one of the two most important freight transport services together with heavy goods vehicles.





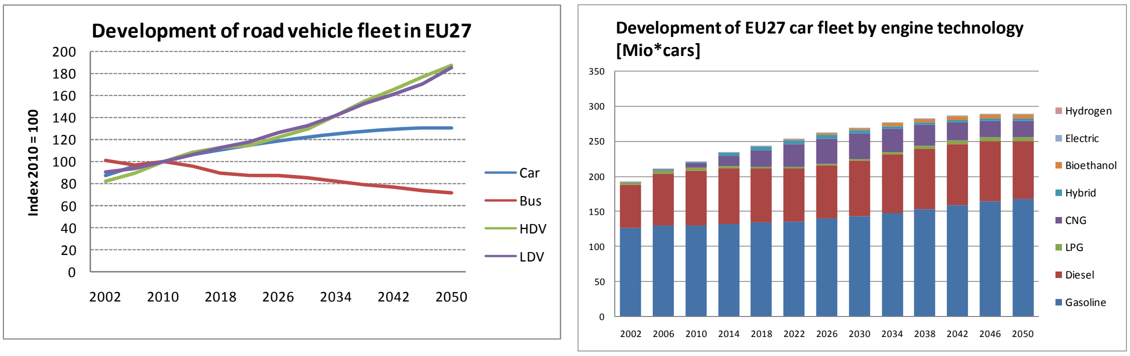
Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-7: Development and structure of freight transport demand in EU27 (Reference Scenario)

The road vehicle fleet develops roughly in line with the transport demand as can be seen in Figure 9-8. The strongest growth is expected for heavy trucks (HDV) and light trucks (LDV), although improved load factors mean that the fleet does not have to grow as strongly as the transport demand. Compared with 2010, these two fleets increase by about 80 %. Over the same period, the bus fleet is reduced by about 15 % and the car fleet increases by about 30 %, which is stronger than the transport performance and reflects both the reduced annual mileage of cars and the reduction of occupancy rates over time.

The composition of the fleet changes slightly. Due to relatively lower fuel prices and the development of the relevant fuelling station network, CNG cars gain market shares after 2010. The trend towards the dieselisation of cars slows down and gasoline cars increase their market share due to larger efficiency potentials and improvements, particularly in the smaller car categories. Hydrogen does not enter the market, and battery electric vehicles occupy only a small niche market, while advanced plug-in hybrids gain a small market share as do bioethanol (E85) cars.

16 In countries featuring IWW, their performances are aggregated into the rail freight mode as the transport characteristics are similar. Thus about 20 % of the rail freight figures refer to IWW, with a declining share in the future.

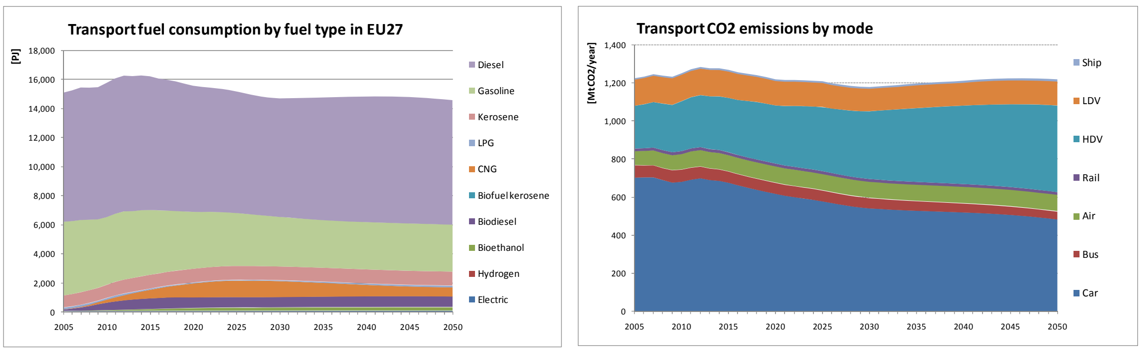


Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-8: Development of vehicle fleets in EU27 (Reference Scenario)

Figure 9-9 presents the energy consumption of transport by type of fuel and the CO_2 emissions by transport mode. It can be observed that both trends are quite stable, which shows that significant efficiency gains are already expected to occur in the Reference Scenario in the transport sector to compensate for the growth in transport demand. The main growth is in freight transport demand so that a shift occurs between freight and passenger energy demand, with freight accounting for 28 % of the energy demand in 2005 and for 40 % in 2050. This means that freight energy demand increases continuously, while passenger energy demand declines after about 2012. These trends can also be observed for fuels, where diesel fuel demand remains more or less stable over the whole period, while gasoline demand is significantly reduced due to efficiency gains of cars and the fuel switch to biofuels and CNG.

Accordingly, the CO_2 emissions from cars fall significantly until 2050, while they increase strongly for heavy duty vehicles, and moderately for air, shipping and rail transport. It should be noted once again here that air transport CO_2 emissions exclude intercontinental flights.



Source: Fraunhofer-ISI, ASTRA calculations

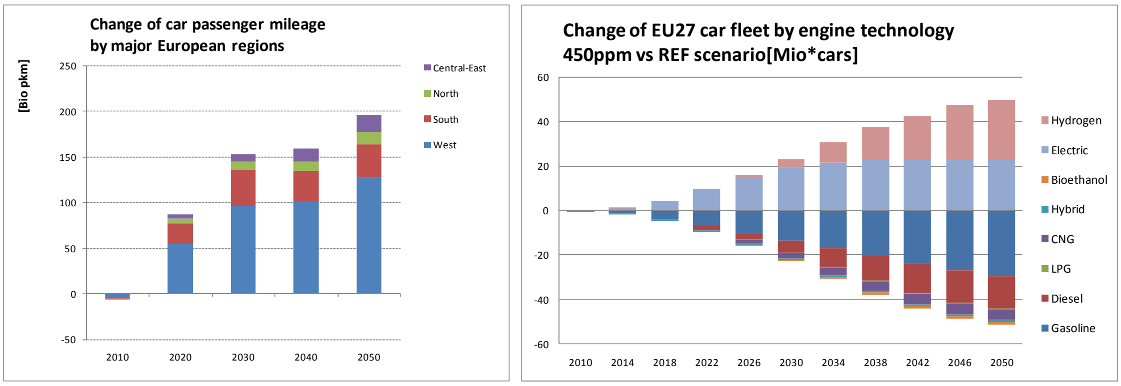
Figure 9-9: Development of transport energy demand and CO_2 emissions (Reference Scenario)

9.3.2 Transport in the 2°C scenarios

The two variants of the 2°C scenario are assumed to build upon each other. A first set of transport-related policies is implemented in the 450 ppm scenario, and then a second set of policies is introduced in addition to these in the 400 ppm scenario.

Passenger and freight transport react in different ways to the policies. The strongest reaction in passenger transport is in the car fleet, while transport performance is adapted only to limited extent. The composition of the car fleet is tackled by several policies leading to an increase of efficiency and a diffusion of new engine technologies, in particular battery electric vehicles and hydrogen vehicles. As Figure 9-10 illustrates, there are about 20 million battery electric city vehicles in the fleet in 2050 as well as about the same number of hydrogen fuel cell vehicles. All other technologies relinquish some of their market shares. In particular, small gasoline cars are strongly affected as these have to compete with the battery electric vehicles

These new technologies as well as the efficiency gains in conventional cars have the effect of increasing the cost of purchasing a car, but at the same time they significantly reduce its running costs. This results in a rebound effect in the order of 2 to 5 % in terms of car passenger transport performance (see Figure 9-10).

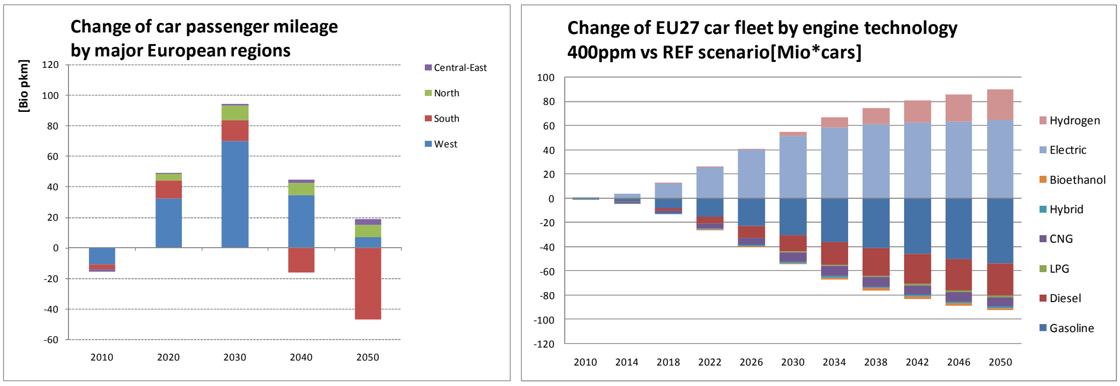


Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-10: Change in car mileage (pkm) and the car fleet in the 450 ppm scenario

The difference in passenger transport in the 400 ppm scenario can be observed in Figure 9-11. The diffusion of new technologies, in particular battery electric vehicles, is reinforced by policies supporting the market entry of electric vehicles and the greater cost of running fossil fuel based cars due to the increase of the CO_2 certificate price. As a result, the number of battery electric vehicles reaches about 60 million in 2050, which means that they become the main type of car used in cities. This is further supported, e.g. by zero-emission requirements in cities.

The increased energy costs resulting from the higher CO_2 certificate prices have the effect of reducing and, in the last decade with the highest prices, even avoiding altogether the rebound effect of increased demand due to efficiency gains.

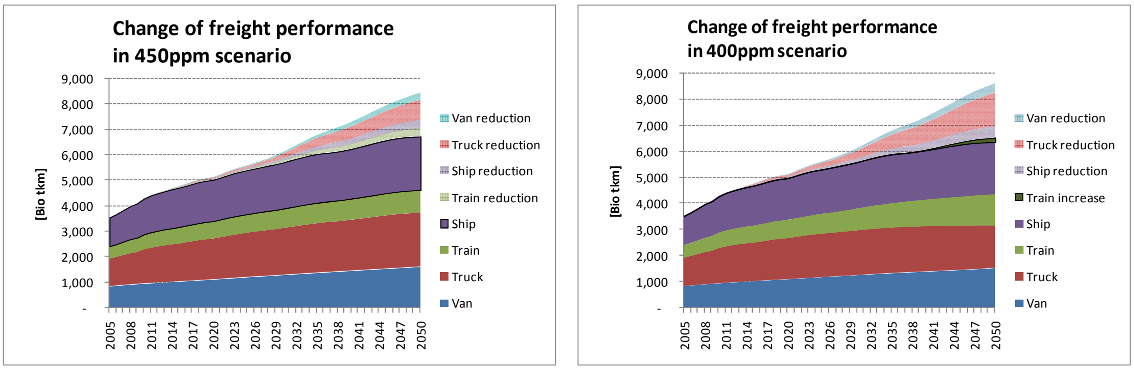


Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-11: Change in car mileage (pkm) and the car fleet in the 400 ppm scenario

For freight traffic, the efficiency of trucks and vans also plays a role as do new engine technologies for vans. However, a demand reduction is also expected and observed here . The first but not the most important reason is the slight reduction of GDP compared with the Reference Scenario which has the effect of reducing freight volumes and consequently also performance.

The second reason is the reduction of freight transport distances due to a number of developments driven by non-transport policies and reinforced by the transport policies. The trend of re-urbanisation concentrates both the centres of consumption and the centres of labour supply, which makes these locations also attractive as production sites, such that transport distances are reduced as a side effect. Further, increased energy prices as well as including the cost of CO_2 force logistics to improve to avoid unnecessary journeys, e.g. to transhipment points and to select instead either fewer transhipments or closer transhipment points. In total, these effects reduce freight transport performance by close to 20 % in the 450 ppm variant and by about 22 % in the 400 ppm scenario. In the 400 ppm scenario, the increased competitiveness of rail due to infrastructure and organisational improvements leads to an additional modal shift of about 5 % in 2050, which further reduces truck transport performance.



Source: Fraunhofer-ISI, ASTRA calculations

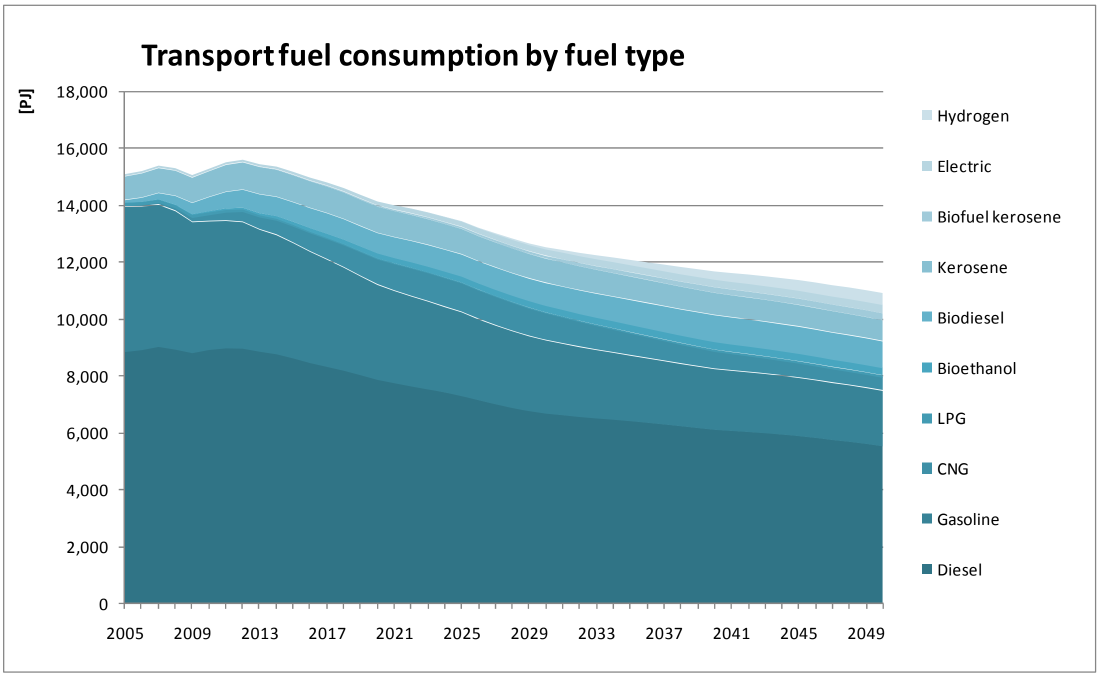
Figure 9-12: Change of freight performance in the 2°C scenarios

The trends described and the transport sector's adaptations to them influence both energy demand and CO_2 emissions in the transport sector. Table 9-2 presents the total transport energy demand for different regions and Figure 9-13 shows the consumption of different fuels in the 450 ppm scenario. In 2050, transport energy demand will be reduced by -24 % compared with the Reference Scenario and by -27 % compared with 2005. Fossil fuel demand is significantly reduced until 2050, while the demand for biofuels, electricity and hydrogen rises. All fossil fuels are decreased, i.e. diesel, gasoline, kerosene, CNG and LPG, though diesel takes the biggest cut of about 70 % (about 3000 PJ). About 40 % of the reduction is from passenger transport and 60 % from freight transport. However, the timing of reductions differs. Passenger transport responds in a faster manner so that a significant reduction is already achieved by 2020 , while the reductions only become significant for freight transport around 2030. The alternative fuels increase to hold moderate shares in 2050 with about 13 % for biofuels, 4 % for hydrogen and 3 % for electricity.

Table 9-2: Changes of transport energy demand on regional level in the 450 ppm scenario

[PJ]	Reference Scenario			2° Scenario (450 ppm)			Changes (450ppm vs. Ref.)		
Country group	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**
North	1,232	1,241	1,258	1,206	1,144	1,021	-2%	-8%	-19%
South	4,325	4,213	3,736	4,184	3,820	2,876	-3%	-9%	-23%
East	1,413	1,559	1,548	1,377	1,442	1,275	-3%	-7%	-18%
West	9,537	9,282	8,759	9,208	8,370	6,366	-3%	-10%	-27%
EU27	**15,781**	**15,579**	**14,593**	**15,265**	**14,114**	**10,928**	**-3%**	**-9%**	**-25%**

Source: Fraunhofer-ISI, ASTRA calculations



Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-13: Transport fuel consumption by fuel in the 450 ppm scenario in EU27

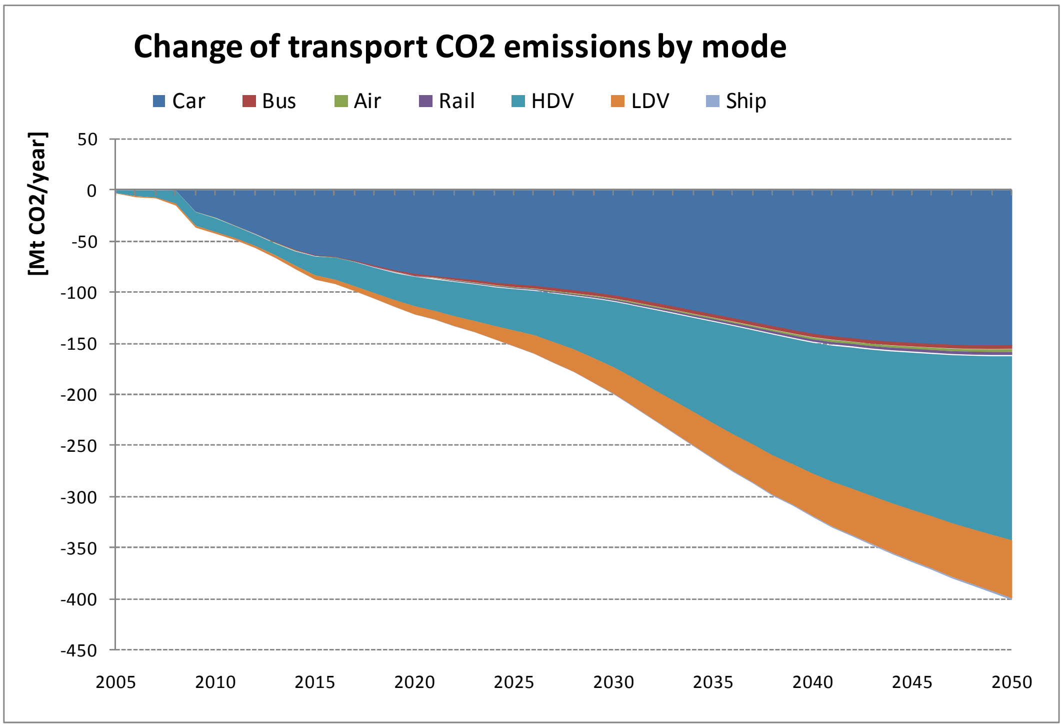
The CO_2 reductions reflect the patterns of energy demand reductions (see Figure 9-14). The largest decrease is observed for heavy duty vehicles. However, car transport contributes about three quarters of the total reductions in 2020 and remains the second most important until 2050. A further significant reduction comes from the efficiency gains of light duty vehicles (LDV) which are stimulated by the CO_2 emission limits imposed on LDVs and the diffusion of electric engines into the LDV fleet which are then used for zero emission city goods delivery.

Since, at no point in time do bus, rail, ship and air transport together emit more than 20 % of the total transport CO_2 emissions, the CO_2 savings from these modes are also smaller than for car and truck transport by one order of magnitude. Thus they are illustrated as a small area in Figure 9-14, contributing altogether less than 4 % of transport CO_2 reductions. Partially, their CO_2 reductions are compensated by demand growth due to the modal-shift from the road modes towards rail and ships.

Table 9-3: Changes of transport CO_2 emissions on regional level in 450 ppm scenario

[Mt CO_2 / year] Country group	Reference Scenario 2010	Reference Scenario 2020	Reference Scenario 2050	2° Scenario (450 ppm) 2010	2° Scenario (450 ppm) 2020	2° Scenario (450 ppm) 2050	Changes (450ppm vs. Ref.) 2010	Changes (450ppm vs. Ref.) 2020	Changes (450ppm vs. Ref.) 2050
North	105	106	114	103	98	86	-2%	-8%	-25%
South	335	328	308	324	296	220	-3%	-10%	-28%
East	109	114	126	106	105	98	-3%	-7%	-22%
West	751	738	763	726	663	501	-3%	-10%	-34%
EU27	**1,242**	**1,228**	**1,250**	**1,203**	**1,109**	**854**	**-3%**	**-10%**	**-32%**

Source: Fraunhofer-ISI, ASTRA calculations



Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-14: Change of CO_2 emissions of transport in 450 ppm scenario in EU27

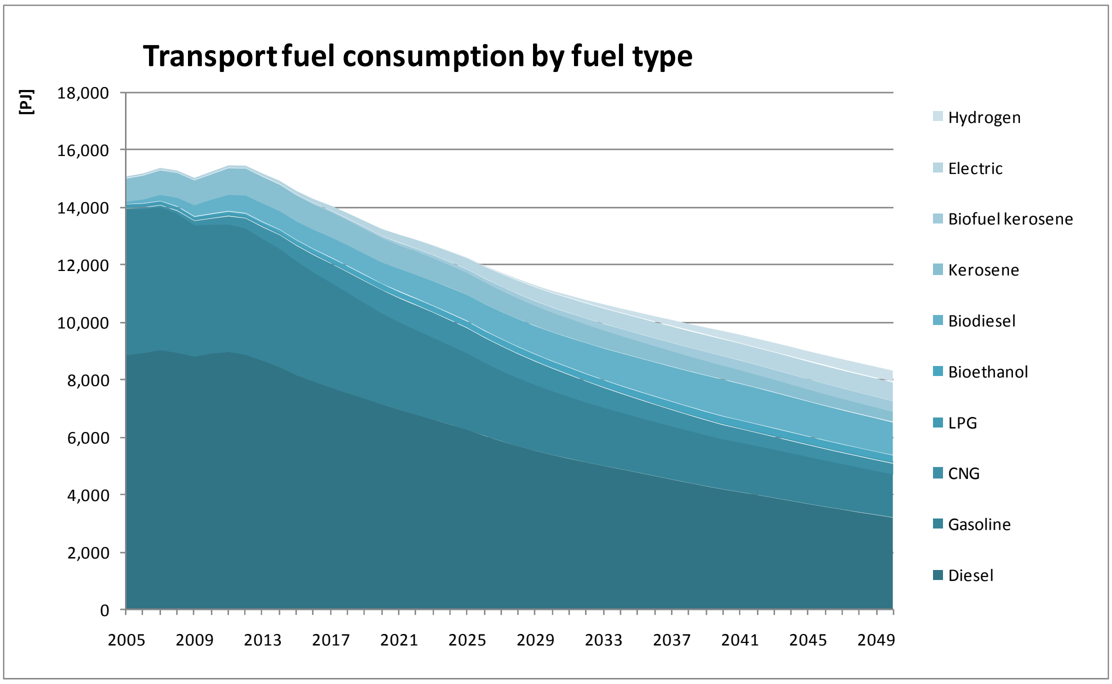
Table 9-4 provides the total transport energy demand and Figure 9-15 the consumption of different fuels in the 400 ppm scenario. In 2050, transport energy demand will be reduced by -42 % compared with the Reference Scenario and by -45 % compared with 2005. Fossil fuel demand is significantly reduced until 2050, while the demand for biofuels, electricity and hydrogen increases. All fossil fuels are decreased, i.e. diesel, gasoline, kerosene, CNG and LPG, although about 65 % (about 5300 PJ) comes from a reduction of diesel. In 2050, about 40 % of the reduction comes from passenger transport and 60 % from freight transport. However, the timing of reductions differs. Passenger transport responds faster so that about

60 % of reductions are due to passenger transport in 2025, while the reductions in freight transport only kick in after this. The alternative fuels increase to higher shares in 2050 with about 21 % for biofuels, 8 % for electricity and 5 % for hydrogen.

Table 9-4: Changes of transport energy demand on regional level in the 400 ppm scenario

[PJ]	Reference Scenario			2° Scenario (400 ppm)			Changes (400ppm vs. Ref.)		
Country group	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**
North	1,232	1,241	1,258	1,204	1,060	782	-2%	-15%	-38%
South	4,325	4,213	3,736	4,177	3,650	2,317	-3%	-13%	-38%
East	1,413	1,559	1,548	1,373	1,341	990	-3%	-14%	-36%
West	9,537	9,282	8,759	9,186	7,818	4,705	-4%	-16%	-46%
EU27	**15,781**	**15,579**	**14,593**	**15,231**	**13,242**	**8,294**	**-3%**	**-15%**	**-43%**

Source: Fraunhofer-ISI, ASTRA calculations



Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-15: Transport fuel consumption by fuel in the 400 ppm scenario in EU27

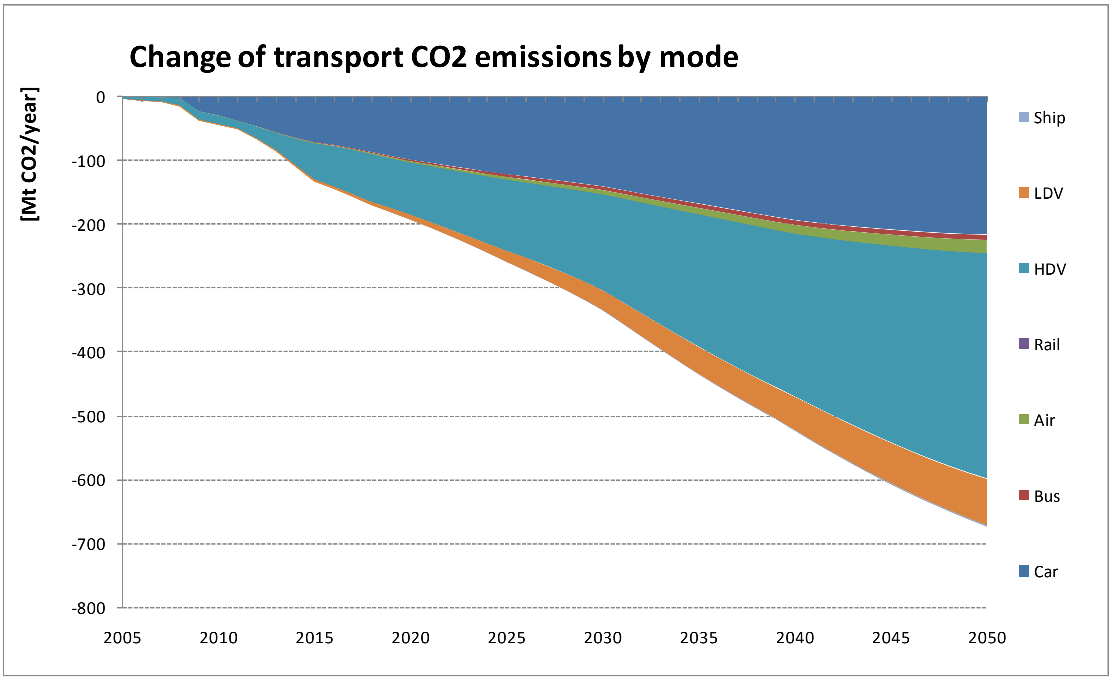
Figure 9-16 illustrates the changes in transport CO_2 emissions in the 400 ppm scenario. Transport reduces its CO_2 emissions by -52 % compared with 2005, which means the applied policy programme does achieve a significant reduction , but not sufficient to achieve -80 % GHG emissions by 2050. 70 % of the additional reduction compared with the 450 ppm scenario is from the freight sector due to the increased use of biofuels, efficiency improvements of HDV and to a large extent from logistics improvements and the modal shift to rail.

In this scenario, air transport also contributes about 7 % reduction compared with the 450 ppm scenario due to the increased use of biofuels and the higher certificate prices added onto the air ticket prices, which reduces demand and gives higher incentives for efficiency improvements in air transport.

Table 9-5: Changes of transport CO_2 emissions on regional level in the 400 ppm scenario

[Mt CO_2 / year]	Reference Scenario			2° Scenario (400 ppm)			Changes (400ppm vs. Ref.)		
Country group	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**
North	105	106	114	103	90	60	-2%	-14%	-47%
South	335	328	308	324	281	162	-3%	-14%	-47%
East	109	114	126	106	97	68	-3%	-14%	-46%
West	751	738	763	725	613	324	-4%	-17%	-58%
EU27	**1,242**	**1,228**	**1,250**	**1,201**	**1,031**	**575**	**-3%**	**-16%**	**-54%**

Source: Fraunhofer-ISI, ASTRA calculations



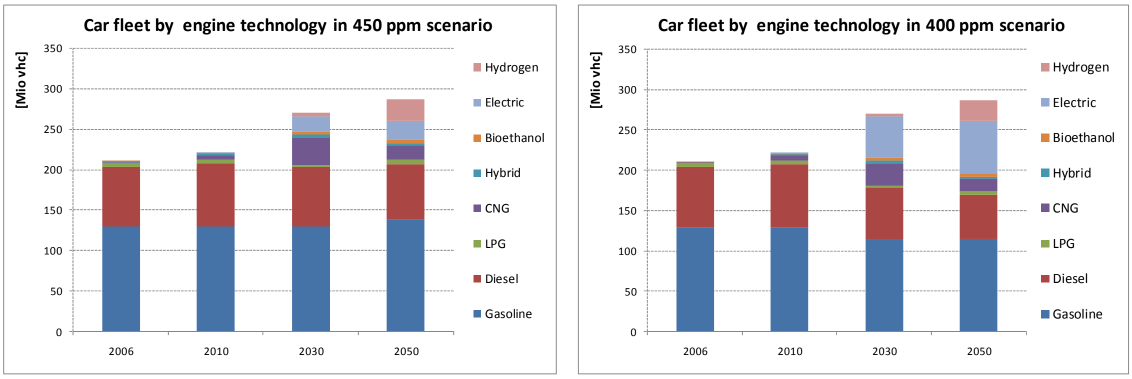
Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-16: CO_2 emissions of transport in the 400 ppm scenario in EU27

The trends for the car fleet can be observed in Figure 9-17. The number of fossil-based cars remains more or less stable in the 450 ppm scenario and drops in the 400 ppm scenario.

However, their average efficiency improves by between 30 and 45 % in the different countries until 2050 compared with 2010. In the medium-term, CNG cars gain a market share of up to 10 % since they represent a suitable option to reduce CO_2 from transport, can also run on bio-methane and provide a bridge to the hydrogen fuel cell technology that enters the car market in the long term. However, for inner city and short distance transport, it is expected that electric cars, i.e. city cars, will enter the market in the short to medium term and gain a significant market share among the smaller car segments. Bioethanol, LPG and advanced plug-in hybrids remain as niche markets for different reasons. Bioethanol suffers from a shortage of fuel supply since it tends to be blended with gasoline rather than sold as a pure oil (or E85). LPG offers too little savings in terms of CO_2 and costs to be really attractive and advanced electric hybrids, i.e. featuring both an electric and a combustion engine, become too heavy and costly and furthermore achieve the highest fuel savings in urban traffic, where they will have to compete with pure electric cars.

The picture is similar for the 400 ppm scenario except that electric cars are even more successful due to more support policies and the higher cost of fossil fuels because of higher certificate prices, with the result that the numbers of fossil-fuelled cars drop over time.

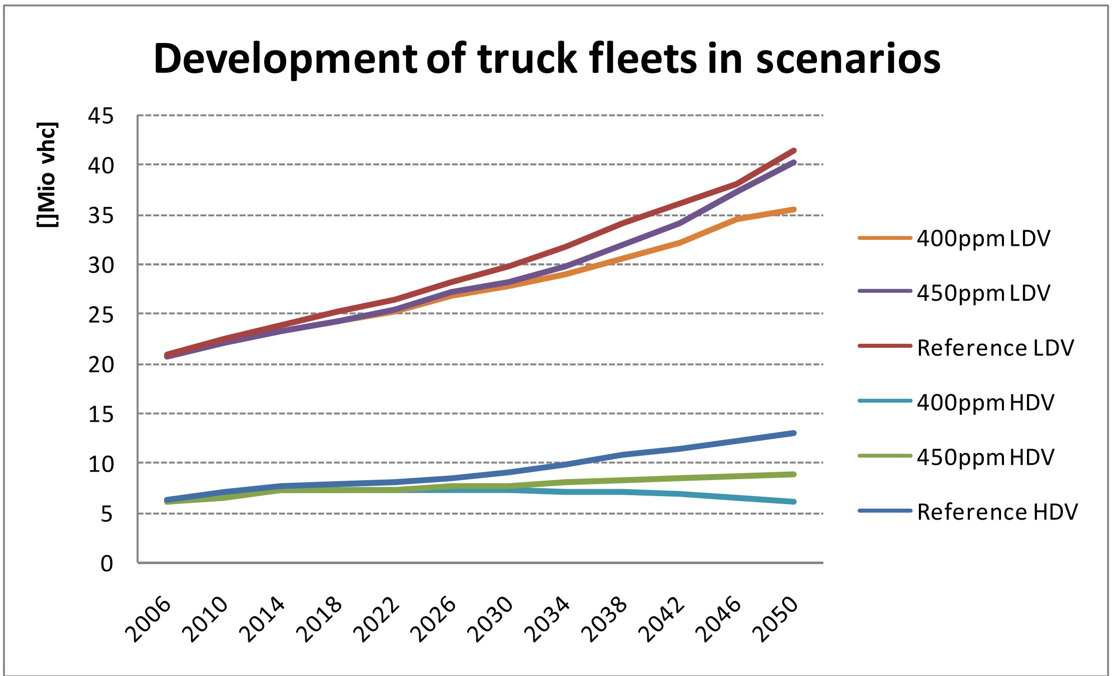


Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-17: Structure of the car fleet in the 450 ppm and 400 ppm scenarios

In contrast to the car fleet, where the number of cars hardly changes across the scenarios, the development of the truck fleet (both LDVs and HDVs) is greatly affected by the policies in the scenarios. Figure 9-18 presents the vehicle stock of trucks in the Reference Scenario and in the two variants of the 2°C scenario. In the Reference Scenario, both truck types increase by about 100 % until 2050 compared with 2006; with a slightly stronger rise in HDVs. In the 450 ppm scenario, road freight performance decreases slightly and a shift occurs from smaller HDVs towards electric LDVs, with the result that the HDV fleet is at a lower level than in the Reference Scenario with an increase of 45 % in 2050. The LDV fleet is about the same in 2050.

In the 400 ppm scenario, there is a more marked reduction in freight performance and the modal shift towards rail and ships is reinforced by their improved competitiveness, so that the HDV fleet in 2050 is about the same as in 2006. LDVs still increase by 70 % compared with 2006, which means the number of LDVs is 30 % smaller than in the Reference Scenario.



Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-18: Impact on truck fleets in the 450 ppm and 400 ppm scenarios in EU27

9.3.3 Mitigation investments in the transport sector

The mitigation policies in the transport sector are influenced by two factors: (1) implementing the policies requires additional investments, which increase the specific cost of transport activities (i.e. the transport cost per pkm or per tkm), and (2) the mitigation policies lead to demand changes and modal shifts which alter the investment patterns of the transport sector. Both investment changes are significant compared with the Reference Scenario and cannot be neglected.

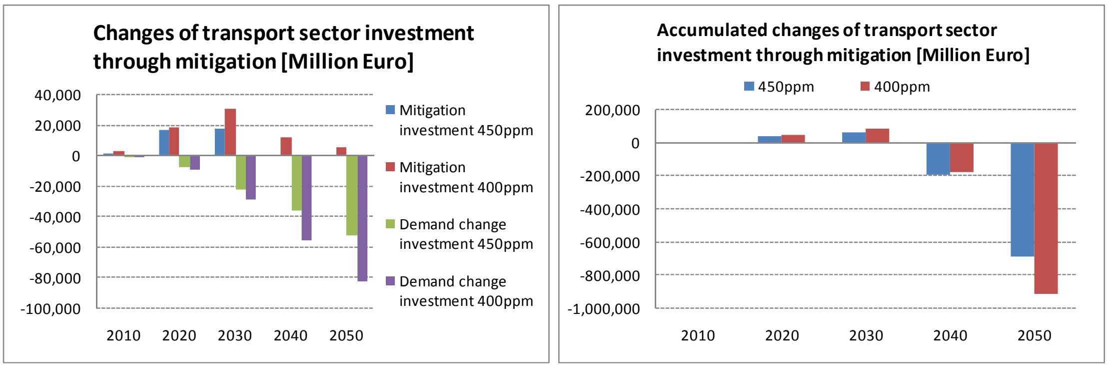
Additional investments are considered for the development of vehicles with higher fuel efficiency, e.g. those required by the CO_2 emission limits for cars, LDVs and HDVs. For cars, the detailed cost increases are taken from TNO [2006] and are in the order of a few 100 euros to about 1500 euros added onto the purchase price. For LDVs and HDVs, the maximum cost increase is estimated to be 1500 and 5000 euros per vehicle, respectively, which corresponds to a vehicle price increase of about 5 %. In addition to this, other additional costs have to be considered, for instance for the use of ultra-fluid lubricants which cost 10€ per filling and are required every two years for each car, for the binding use of low resistance tyres for trucks, which are assumed to cost 10 % more than standard tyres and have a 10 % shorter lifetime.

About 2 billion euros additional investments in rail systems are also required each year in the EU27 to improve the competitiveness of passenger rail by adding 3000 km of high-speed lines (built over 30 years), provide better connections at stations and improve the attractiveness of stations. In addition, the competitiveness of freight rail has to be improved by adding 3000 km of dedicated freight rail track (built over 20 years), eliminating bottlenecks caused either by (1) competition between freight and passenger rail transport or (2) direct capacity limits for rail freight transport (e.g. in seaport-hinterland connections) and implementing additional, multi-modal terminals.

The impact of the demand changes have already been described in the previous section. The car fleet remains more or less the same with only about -1 % reduction in the 2°C scenarios and a moderate downsizing of cars, but the EU27 truck fleet is significantly reduced by -10 % in the 450 ppm scenario and -24 % in the 400 ppm scenario in 2050. In particular, the changes in the truck fleet reduce the investments required for vehicles in the transport sector, although increased demand for rail transport requires increased investments in locomotives and engines. After 2030, a strong reduction of transport-related vehicle investment can be observed.

Figure 9-19 shows the investment increase by mitigation measure, the reduction of transport investment due to demand changes (left-hand side) and the accumulated changes in investment over time (right-hand side). It is clear that the mitigation investments in the 450 ppm scenario occur earlier (between 2015 and 2035, with a peak of €18 billion in 2022), while the peak in the 400 ppm scenario is around 2030 (peaking at €30 billion) and that significant mitigation investments are required to drive down the GHG emissions of transport after this point until 2050.

On the other hand, the adaptations of investment due to changes in transport demand increase continuously following the path of continuously increasing load factors and the modal shift away from roads. They reach a maximum in 2050 with about €-52 billion and €-82 billion in 450 ppm and 400 ppm scenarios, respectively. Looking at the accumulated balance of the investment changes in the 2°C scenarios (right-hand side of Figure 9-19), it is apparent that, until around 2033, additional mitigation investments are required in the transport sector (with a respective peak of €68 billion and €80 billion in the 450 ppm and the 400 ppm scenario). After this point, the accumulated investments in the transport sector are lower than in the Reference Scenario.



Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-19: Impact of the 2°C scenarios on transport investment in EU27

Translating the mitigation investments for trucks into an average cost change per tkm, it appears that costs increase moderately during the first two decades by about 1 cent/tkm (or about +8 %). In the long term, road freight transport costs actually decrease by about 3 cent/tkm due to energy and CO_2 efficiency improvements.

9.3.4 Impact of policies in the 2°C scenarios

A model-based analysis performed with a simulation model like ASTRA enables simulations of scenarios to be run with and without selected measures (i.e. policies or technological changes). This feature is used in ADAM to run simulations of the 450 ppm and 400 ppm scenarios in which a selected number of measures are excluded (switched-off) from the scenario. We call such a scenario a 'switch-off scenario'. The results of the 450 ppm switch-off scenarios can be compared with the full implementation of measures in the 450 ppm scenario to identify the impact of individual measures. It should be pointed out that the simulation could be done using a different approach, i.e. by taking the Reference Scenario and adding only one measure to identify its impact. However, the results would not be the same and it is more appropriate to apply the switch-off analysis as the measures then unfold their effects within the frame of interaction with the other measures of this scenario. Further, adding the impacts of all the switch-off analyses together and assuming that there are no synergies between the measures, one should reach the level of indicators (e.g. energy demand) in the Reference Scenario. This is not the case which demonstrates implicitly the existence of synergies between the measures. Accordingly, the switch-off analysis includes one category of impacts which is called synergies.

Since more than 20 measures have been implemented in the transport sector, measures were grouped together to produce a limited number of thematic packages in order to reduce the number of required simulations. The following packages were defined for the switch-off analysis in the 450 ppm scenario:

- 'Efficiency package switch-off' includes CO_2 emission limits for cars, CO_2 emission limits for LDVs, reactions of truck load factors to fuel cost increase (including CO_2 prices of certificates), binding regulation of low resistance lubricants.
- 'Biofuels package switch-off' includes biofuels for road transport only as in the Reference Scenario; no biofuels at all for rail or air transport.
- 'Fuel switch package switch-off' includes electric car diffusion only as in the Reference Scenario, no hydrogen cars and no hydrogen filling station network, no electric LDVs.
- 'Demand shift package switch-off' includes no CO_2 efficiency labelling of cars, no inclusion of transport into ETS, i.e. no CO_2 costs aggregated into the cost parameters of any of the modes.

Since additional measures were implemented in the 400 ppm scenario, the packages in the switch-off analysis include those listed above plus:

- Efficiency package switch-off also includes no binding regulation for low resistance tyres for trucks, no special training for HDV truck drivers.
- Biofuels package switch-off also includes no increased quotas of biodiesel for road or of biofuel for air transport.
- Fuel switch package switch-off also includes no increased diffusion of electric cars, i.e. diffusion only as in the Reference Scenario.
- Demand shift switch-off package further includes no increased competitiveness of rail due to investment and organisational innovations and thus no modal shift of long distance freight and passenger transport to rail. No inclusion of the higher CO_2 cost in transport costs.

Figure 9-20 provides the results of the switch-off analysis for the total energy demand in the 450 ppm and 400 ppm scenarios. The lowest dark area represents the energy demand in the 450 ppm and 400 ppm scenario, respectively. Each switch-off element increases the energy demand towards the level of the Reference Scenario, which is represented by the upper curve of the topmost area (the synergies area). Looking at the 450 ppm scenario (left-hand side), one can observe two key features of the switch-off packages: (1) the order of magnitude in relation to each other, and (2) the time profile of package impacts.

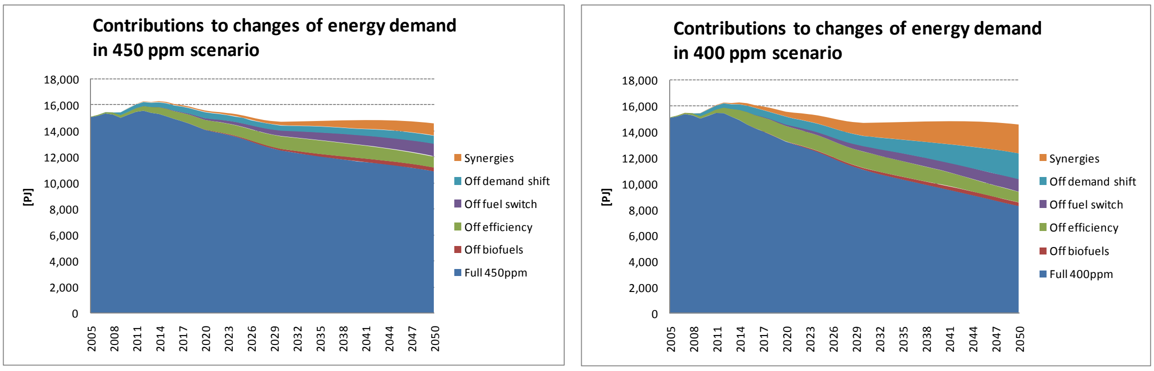
In the 450 ppm scenario, the most effective element is the efficiency package, i.e. in particular, the CO_2 emission limits for cars and light duty vehicles. Such a binding regulation is not only effective, but also provides the framework for a competitive market to develop efficient vehicles. In other words, (1) it provides certainty for the investment decisions of vehicle manufacturers (they can be certain they have to develop efficient cars and will not lose any R&D investments in efficiency improvements), and (2) the free-rider argument does not hold anymore, i.e. the argument that a manufacturer is not able to develop efficient cars even though they might want to because their competitors are continuing to sell high-powered, fast cars which would sell better than fuel-efficient ones (at least in the past).

In the medium to long run, the fuel-switch, i.e. the market penetration of electric cars and vans as well as hydrogen cars plays the second most important role. Here, it has to be taken into account that only moderate market penetration is achieved in this scenario and that the energy savings are proportional to the market shares gained by these new technologies. The demand shift plays a limited role as labelling only has a potential of 2-4 % savings, and including the transport sector in the ETS with certificate prices of up to 80€/t CO_2 only increases the fuel cost for diesel or gasoline by about +10 % and by about +20 % for kerosene, because no other taxes are added here. Further, fuel costs play the largest role for air transport compared with the other modes. Accordingly, air transport experiences the highest impact of -5 % reduction of passenger performance.

Biofuels only have a very limited effect on energy demand as they mainly replace one type of primary energy input (i.e. fossil fuels) by a similar type of input (i.e. bioethanol or biodiesel). A more important role can be observed for the synergies in the medium to long term. The causes of synergies are difficult to identify analytically. One reason may be that the modal shift is augmented by adding different policies, e.g. the diffusion of electric engines reduces energy demand and leads to a new modal split between modes as well as between car engines. This is also affected when the cost of CO_2 certificates are added onto fossil fuels, such that fewer gasoline and diesel cars are bought and more electric cars, which then further reduces the energy demand compared with the efficiency package switch-off and thus constitutes one of the reasons for synergies. In 2050, the synergies are nearly equally as important as the efficiency and the fuel switch packages.

Looking at the 400 ppm scenario, two major changes can be observed. The demand shift plays a much larger role than in the less ambitious 450 ppm scenario and in the long run actually delivers the largest contribution to energy saving. This has two explanations: First, investments in and organisational improvements of rail transport increase its competitiveness significantly. Second, the higher CO_2 price of up to 200 €/t CO_2 increases kerosene price by close to 50 % such that, e.g. air transport suffers a loss of more than 20 % of demand compared with the Reference Scenario.

A similar large contribution to the reductions is made by the synergies, which also enfold over the medium to long term. The contribution of the efficiency measures increases by about one third compared with the 450 ppm scenario.

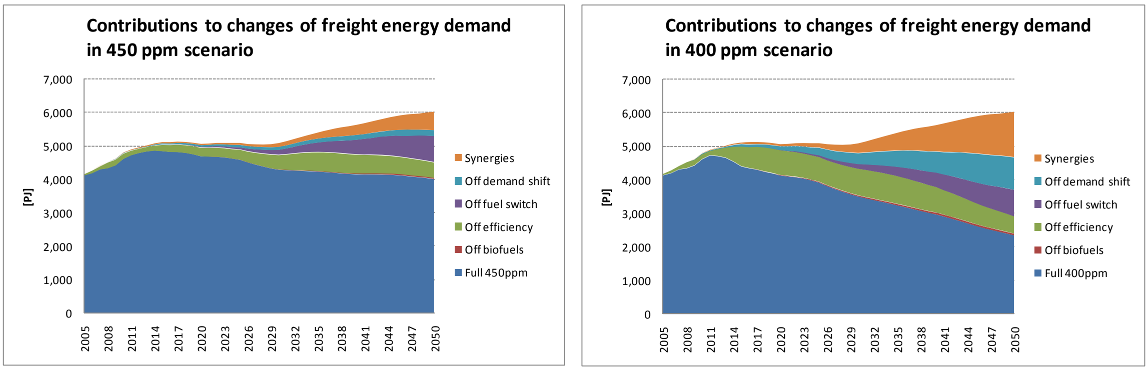


Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-20: Switch-off impacts on energy demand in the 450 ppm and 400 ppm scenarios

Figure 9-21 shows the energy demand impacts for freight transport based on the approach explained above. First, it should be noted that the 450 ppm scenario enables to shift freight energy demand from a growth path to a stable path. In the 450 ppm scenario, again efficiency measures make the largest contribution. The impact of any other measure only unfolds in the medium to long term showing that fuel switching, i.e. the introduction of electric LDVs, plays a significant role, while demand shift and biofuels have almost no impact on energy demand of freight transport.

In the 400 ppm scenario, freight energy demand is also reduced by -43 % compared with 2005, i.e. freight energy demand is also put on a declining path. This is achieved by increased efficiency measures which now also address HDV freight transport and thus nearly double the efficiency savings of freight transport in 2030 (medium term). In the long term, the modal shift towards rail freight and shipping plays an even larger role than efficiency measures, which was also observed for the whole transport sector above. This confirms once again that aligned push-pull strategies are needed to shape transport in a climate-friendly manner. In this case. the pull strategy is the improved competitiveness of rail and the push strategy comprises higher CO_2 prices and the higher relative energy demand per unit of truck transport compared with rail. Also, as observed above, synergies play a large role, particularly when demand shift measures already contribute a significant share of energy demand reductions.

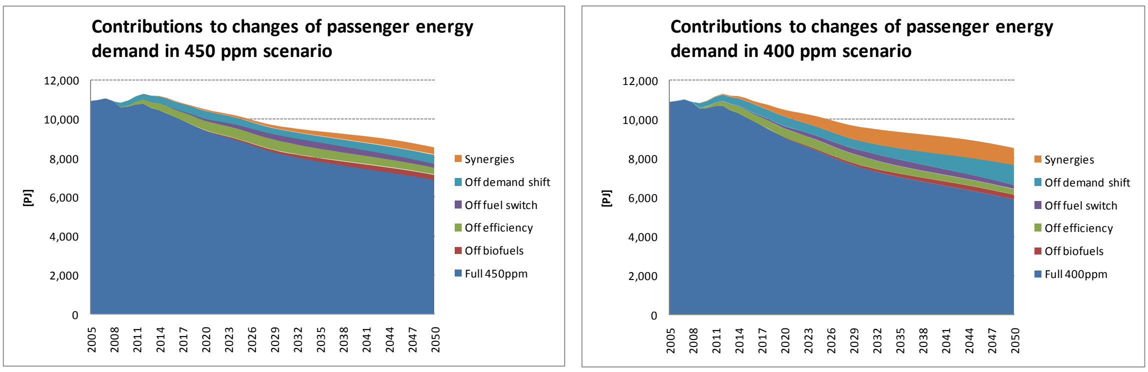


Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-21: Switch-off impacts on freight energy demand in the 450 ppm and 400 ppm scenarios

Figure 9-22 presents the corresponding figures for the switch-off analysis of passenger transport. Since passenger transport in the Reference Scenario already includes efficiency gains that, together with a stable demand, generate a declining energy demand path, the further reductions of passenger energy demand are smaller than for freight. Efficiency and demand shift play the largest role in passenger transport. The demand shift reduces the share of air transport and to lesser extent also car transport and increases the shares of slow modes, train and bus transport.

In the 400 ppm scenario, the demand shift becomes even more relevant as air transport has to bear the highest cost impacts of the CO_2 certificate prices and rail transport benefits from infrastructure and organizational improvements and increases its competitiveness and thus its modal share. Again, synergies are important as is a higher significance of the demand shift in generating energy reductions.



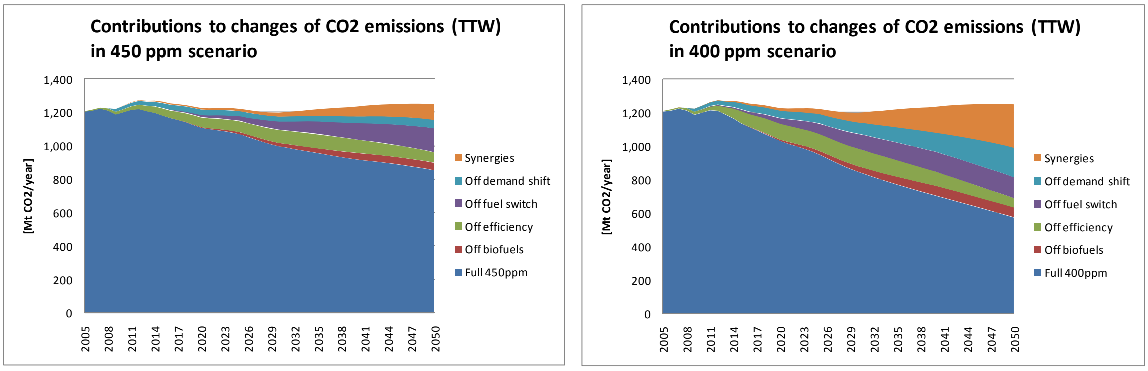
Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-22: Switch-off impacts on passenger energy demand in the 450 ppm and 400 ppm scenarios

Figure 9-23 presents the results of the switch-off analysis for the transport CO_2 emissions. In general, they confirm the results of the energy-related analysis above. Two major differences concern the fact (1) that biofuels actually contribute to CO_2 savings, and (2) that the fuel switch plays a larger role than it does for energy demand.

In both cases, one should mention the specifications under which the CO_2 emissions were calculated in the ASTRA model.[17] The CO_2 emission savings are not estimated considering different pathways for their production, but are considered as average savings of CO_2 per unit of fuel. This average saving starts at about 50 % and rises to 65 % in 2050 for bioethanol, which is optimistic for the first decade and rather pessimistic for the medium- to long-term future, which could see the use of second (e.g. straw and use of residues and whole plants) and even third generation biofuels (e.g. algae fed by CO_2) so that the CO_2 savings from biofuels could be even higher in the medium and long run than shown in the figures.

In the case of fuel switching, one has to note that the figures show the tank-to-wheel emissions (TTW). That is, for electricity and hydrogen, the CO_2 emissions are calculated as zero. ASTRA also estimates the upstream emissions (well-to-tank) of these fuels. The figures show that about two thirds of the area shown constitute actual CO_2 savings for fuel switching, while about one third is generated upstream.



Source: Fraunhofer-ISI, ASTRA calculations

Figure 9-23: Switch-off impacts on transport CO_2 emissions in the 450 ppm and 400 ppm scenarios

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[17] The main results concerning CO_2 savings in our work came from the EuroMM model in the conversion sector, which aggregates all the energy demands and considers the different production pathways, e.g. for biofuels. However, for the detailed transport analyses, the internal ASTRA results have to be taken since the described switch-off simulations were only performed with the ASTRA model.

9.4 Conclusions about policies to achieve changes in transport sector

Including transport in the EU-ETS is not sufficient to transform it into a low carbon and climate-friendly activity. The time scales of market-based choices (one to four years), to which an ETS system belongs, are too short to introduce the required changes of technologies, organisations and behaviour and the time lag between adapted choices and their impacts on GHG emissions is often too large so that new choices have to be anticipated years or even decades before they become effective in reducing the GHG emissions of transport. Thus besides including transport in the EU-ETS, a package of transport-focussed policy measures has to be implemented, including regulation, taxation, R&D support and information campaigns. One main issue is that policy-makers have to make it very clear to decision-makers in companies and households that climate protection policies in the transport sector are not a short-term policy fashion, but will be pursued forcefully and over the medium and long term.

The 2°C scenario results of implementing 22 different measures for transport have shown that transport energy demand can be reduced by -27 % and -45 % in the 450 ppm and the 400 ppm scenarios, respectively, until 2050 compared with 2005and that this can feasibly be done with still moderate policy packages,. In terms of transport CO_2 emissions reductions until 2050, this is equivalent to CO_2 reductions of -30 % and -52 % compared with 2005.

The impact analysis of the different measures' contributions to reductions has revealed that, in the short to medium term (3 to 20 years), energy efficiency measures contribute the largest reductions. In particular, CO_2 emission limits for cars and light duty vehicles play a large role in reducing the energy demand and CO_2 emissions of transport. As a side-effect, they also reduce the dependency on fossil fuels, which could already become an important issue within this time horizon.

In the medium- to long-term perspective (20 to 40 years), two other measures play a larger role. These are the fuel switch (i.e. the introduction of electric vehicles and hydrogen fuel cell vehicles into transport) and the demand shift (i.e. improved logistics and competitiveness of rail as well as including transport in an ETS system with CO_2 certificate prices well above 100 €/t CO_2). Both need strong political support, the former via the support of R&D and early market diffusion (e.g. feebates) and the latter by supporting the creation of an interoperable European rail network featuring a backbone of high-speed rail for passenger and dedicated freight links at bottlenecks together with improvements of intermodal logistics as well as including transport in a global CO_2 ETS system.

Considering that the emerging policy objective is to reduce GHG emissions by -80 % by 2050, it seems that our estimated reductions of transport emissions would still fall short compared with what is needed for climate protection. However, there are both some supporting trends of CO_2 reductions not fully operationalized in our analysis and other additional policies that could be realised to achieve the climate policy target. As a first trend, re-urbanisation should be mentioned. Cities are becoming greener with many attractions in terms of culture, education, childcare and healthcare services so that a growing number of people will move back into cities from the suburbs or even rural areas. Since cities are able to offer more carbon lean transport than suburbs or rural areas, this trend will help to reduce CO_2 emissions from transport. Of course, this also needs support in the sense that cities have to promote multi-modality, i.e. increased use of bikes, bike- and car-sharing systems, the latter ideally based on a fleet of highly efficient conventional or electric city cars and both combined with a comfortable and reliable public transport system. It must be possible to use all of these transport options with just one mobility card. If necessary, e.g. to fund the set-up of such a system and to add a push measure, city tolls should be considered to reflect the scarcity of infrastructure and urban space as well as clean urban air.

In addition, a number of soft factors also play a role. One example is the advertising strategies of European car manufacturers who tend to invest more in advertising fast, powerful cars than they do in adverts for fuel-efficient small and midsize cars [DENA 2009]. If this past trend also reflects the future development strategy of European car manufacturers, they run the risk of losing the market segment of fuel-efficient cars to Asian manufacturers, who have clearly defined the small, efficient and still affordable car as their main development goal. Given the constraints of limited fossil fuel resources and the need for climate protection, this represents precisely the car market segment with the − largest demand in the future, while continuing to pursue the strategy of horsepower and speed will lead European manufacturers directly into a blind alley.

10 Renewables sector in Europe

10.1 Target of the analysis

Primary energy conversion based on renewable energy sources (RES) is projected by different models up to the year 2050. The agent-based simulation model PowerACE-ResInvest covers the projection of grid-connected energy conversion plants using renewable energy sources (pure electricity generation, CHP and biomass district heating plants). As opposed to conventional approaches based on equilibrium or optimisation models, agent-based simulation (ABS) takes into consideration market imperfections, e.g. strategic behaviour, asymmetric information and non-economic influences (cf. Gilbert 2007; Weiss 2000; Wooldridge 2005). It investigates macro-level issues in a bottom-up approach by analysing interactions on the micro-level (Ma, Nakamori 2005). These interactions on the micro-level comprise the decentralised decisions of and interactions between heterogeneous actors or agents in a system (Janssen, Ostrom 2006).

PowerACE-ResInvest covers the EU as a whole and focuses on the simulation of potential RET-pathways including centralised installations up to 2050. The central concept of PowerACE-ResInvest consists in individual investment decisions for RET-projects from an investor's perspective. That is, the investor calculates the expected net present value of a potential project taking into account dynamic cost-resource curves and existing financial policy support. Investment decisions are based on the financial premiums available for RET and the techno-economic characteristics of RETs. Main characteristics include the available resource potential and the corresponding energy conversion costs, or by the technology-specific cost-resource-curves. In the case of wind onshore, detailed cost-resource curves have been derived, which combine land availability and wind regimes in a geographical information system (see Held et al. 2008). Technology learning is modelled endogenously within the model based on the experience curve concept. The model focuses on the development of RET-options in the EU and does not take into account possible imports of green electricity from other countries such as electricity imports from concentrating solar power in North Africa.

This chapter provides a comparison of the model runs of the 2° Scenario with results from the Base Case. As the share of renewables in the electricity mix already reaches very high levels in case of the 450ppm Scenario, we assumed no further increase in case of the 400ppm Scenario. Thus, only one climate mitigation scenario is described subsequently. For a description of the detailed scenario assumptions of the Base Case Scenario for renewables, the reader is referred to Jochem et al. (2007). Details about the future development of renewable energy sources in case of climate change adaptation can be found in (Reiter et al. 2009; Jochem et al., 2008).

In contrast, the development of non-grid connected heat production (geothermal heat pumps and solar thermal collectors) is projected by the demand-driven final energy models SERVE, RESIDENT, ASTRA, and ISI-INDUSTRY for the corresponding final energy sectors (see Chapter 6, 7, 8 and 9). Non-grid based heat production using wood fuel is handled by MATEFF (see section 5).

10.2 Basic assumptions on technologies

The basic assumptions for renewable conversion technologies in the 2° Scenario are similar to those undertaken within the Base Case and the Reference Scenario. Techno-economic data of the technologies (see Table 10-1), the status quo of RES-E in 2005 remain completely the same (see Jochem et al. 2007).

10.3 The potential contribution of renewable energy sources to mitigating climate change in centralised installations

10.3.1 Assumptions for electricity generation by renewables - 2° Scenario

As the possible use of RET depends in particular on the available resources and the associated costs renewable energy potentials have been assessed in a very detailed manner (see Table 10-2). Thereby, all potentials have been assessed in a bottom-up procedure using country specific assumptions, e.g. on agricultural land availability, shares of landfill, land availability for PV or solar thermal electricity generation. The potentials for wind onshore are based on a geographical information system (GIS) assessment. The resulting geographically explicit full-load hours for wind onshore represent one of the main determinants of wind power economics.

Table 10-1: Technical and economic characteristics of RET in 2005

Technology	Plant specification	Investment	O&M costs	Electric efficiency	Heat efficiency	Life-time	Typical plant size
Units		[€/kWel]	[€/ (kWel*yr.)]	[-]	[-]	[years]	[MW_{el}]
Biogas	Agricultural biogas plant	2,550 - 4,290	115 – 140	0.28 - 0.34	-	25	0.1 - 0.5
	Agricultural biogas plant – CHP	2,760 - 4,500	120 – 145	0.27 - 0.33	0.55 - 0.59	25	0.1 - 0.5
	Landfill gas plant	1,280 - 1,840	50 – 80	0.32 - 0.36	-	25	0.75 – 8
	Landfill gas plant – CHP	1,430 - 1,990	55 – 85	0.31 - 0.35	0.5 - 0.54	25	0.75 – 8
	Sewage gas plant	2,300 - 3,400	115 – 165	0.28 - 0.32	-	25	0.1 - 0.6
	Sewage gas plant – CHP	2,400 - 3,550	125 – 175	0.26 - 0.3	0.54 - 0.58	25	0.1 - 0.6
Biomass	Biomass plant	2,225 - 2,530	75 – 135	0.26 - 0.3	-	30	1 – 25
	Co-firing	550	60	0.37	-	30	-
	Biomass plant – CHP	2,600 - 4,230	80 – 165	0.22 - 0.27	0.63 - 0.66	30	1 – 25
	Co-firing – CHP	550	60	0.2	0.6	30	-
Biowaste	Incineration plant	4,300 - 5,820	90 – 165	0.18 - 0.22	-	30	2 – 50
	Incineration plant – CHP	4,600 - 6,130	100 – 185	0.14 - 0.16	0.64 - 0.66	30	2 – 50
Geothermal electricity		2,000 - 3,500	100 – 170	0.11 - 0.14	-	30	2 – 50
Hydro large-scale		850 - 5,950	35	-	-	50	20 – 250
Hydro small-scale		800 - 6,050	40	-	-	50	0.25 – 10
Photovoltaics		4,000 - 6,100	38 – 47	-	-	25	0.005 - 0.05
Solar thermal electricity		2,880 - 4,465	163 – 228	0.33 - 0.38	-	30	2 – 50
Tidal energy		2,670 - 3,025	44 – 53	-	-	25	0.5 – 2
Wave energy		2,135 - 2,850	44 – 53	-	-	25	0.5 – 2
Wind onshore		890 - 1,100	33 – 40	-	-	20	2
Wind offshore		1,590 - 2,070	55 – 68	-	-	20	5

Source: (Ragwitz, Resch 2006). In case of PV: (Staiß 2007)

Table 10-2: Technical potentials for renewable energies generating electricity, EU27, 2° Scenario, 2050

	Electricity Generation Potential [PJ]						Primary Energy Potentials[18] [PJ]
	Wind	Solar	Geothermal (hydrothermal)	Hydro	Wave &Tide	**Total (excl. BM)**	**Biomass**
Austria	35	94	0	157	0	**287**	**305**
Belgium	107	56	0	1	1	**164**	**105**
Luxembourg	4	6	0	0	0	**11**	**5**
Bulgaria	26	122	5	46	3	**203**	**240**
Cyprus	7	12	0	0	1	**20**	**12**
Malta	1	7	0	0	0	**8**	**1**
Slovenia	2	20	0	30	0	**52**	**108**
Czech Republic	196	105	0	11	0	**312**	**184**
Germany	746	544	0	91	28	**1,408**	**1,605**
Denmark	661	60	0	0	9	**730**	**171**
Estonia	132	23	0	0	4	**160**	**98**
Latvia	98	50	0	15	2	**165**	**153**
Lithuania	31	69	0	3	1	**104**	**274**
Spain	893	954	0	138	48	**2,033**	**891**
Finland	229	48	0	56	6	**339**	**491**
France	1,420	795	1	213	47	**2,476**	**1,566**
Greece	89	149	1	24	14	**277**	**188**
Hungary	11	158	0	5	0	**174**	**212**
Ireland	674	77	0	3	14	**769**	**53**
Italy	209	650	6	177	12	**1,055**	**775**
Netherlands	254	83	0	0	4	**341**	**128**
Poland	385	415	0	11	4	**815**	**1,252**
Portugal	309	169	1	34	27	**539**	**212**
Romania	49	395	0	94	2	**541**	**302**
Sweden	1,253	73	0	274	11	**1,611**	**638**
Slovakia	21	63	0	20	0	**104**	**146**
United Kingdom	2,144	418	0	19	212	**2,792**	**874**
EU-27	**9,987**	**5,616**	**14**	**1,426**	**448**	**17,491**	**10,990**

Source: Own calculations and estimations, partially based on European Environment Agency (2006); Ragwitz et al. (2006)

As an overall framework to define and analyse the climate change mitigation scenario we base our calculations on the emission cap derived from the global Poles model. Since CO_2

18 The biomass primary energy potential includes the potential for grid-connected energy conversion plants (pure electricity generation plants, CHP plants and district heating plants). The potential for non-grid connected heat production based on biomass is excluded in this table, but has been considered separately in Chapter 6 in the final energy sectors.

emissions and their impact on the global mean temperature are locally independent, this link to the Poles model is needed to achieve reliable estimates for total CO_2 emissions which are allowed for Europe. With the given emission cap, we can estimate the measures and costs which are necessary in Europe to transform the energy sector. Some of the necessary reductions in CO_2 emissions are achieved in the final energy demand sectors. As we use the energy demand in terms of exogenous model input, we focus on policies implemented in the renewable sector. Policies applied to achieve reductions in energy demand are described in more detail in Chapter 6 - 9.

With regard to the renewables sector, we assume the application of reinforced policy measures compared to those active in the baseline scenario. In this way, we calculated a hypothetical financial support value reflecting the economic value of CO_2 that can be avoided by the use of low-carbon technologies using two iterations.

For this purpose we calculated the current average CO_2 emissions per unit of electricity generated for the current electricity mix at country level in a first step. We assumed that this value corresponds to the amount of CO_2 emissions that can be avoided by the use of RES as a first estimation. Multiplied with the CO_2 price, which has been taken from POLES, we obtained a first estimation of the potential benefit of using RES regarding their potential CO_2 avoidance. Since a first comparison of these CO_2 prices with the results from EuroMM showed significantly lower CO_2 prices, we decided to use 60% of the certificate price identified by POLES (see section 12.1 for further explanations). Finally, the economic value of CO_2 avoidance is added to the wholesale electricity price and results in the total remuneration level available for RES in the electricity sector (RES-E). Since the electricity mix was assumed to be constant, this iteration represents a static calculation.

The second iteration estimates the same value in a dynamic way. Thereby, the results of PowerACE-ResInvest are integrated into a first EuroMM run. Based on these results, we recalculated the value of avoided CO_2, but this time based on the conventional power capacity displaced by RES. The final value of avoided CO_2 shows (see Figure 10-1) that this value differs on a national basis. Starting in 2040 it amounts to 0 in some countries (AT, FR), as no conventional electric power with relevant CO_2 emissions is replaced by RES. The CO_2 price marks the maximum limit for this value. As long as the value of avoided CO_2 does not allow for a sufficient remuneration level for profitable investments in renewables, the financial support as described in the baseline scenario is available. Once the remuneration from the value of avoided CO_2 and the electricity price exceeds the feed-in tariffs in place, potential investors tend to choose the support option with a higher remuneration level. If no financial support is available for a certain technology in a country, the wholesale electricity price (excl. taxes) represents the possible turnover per unit of electricity generated.

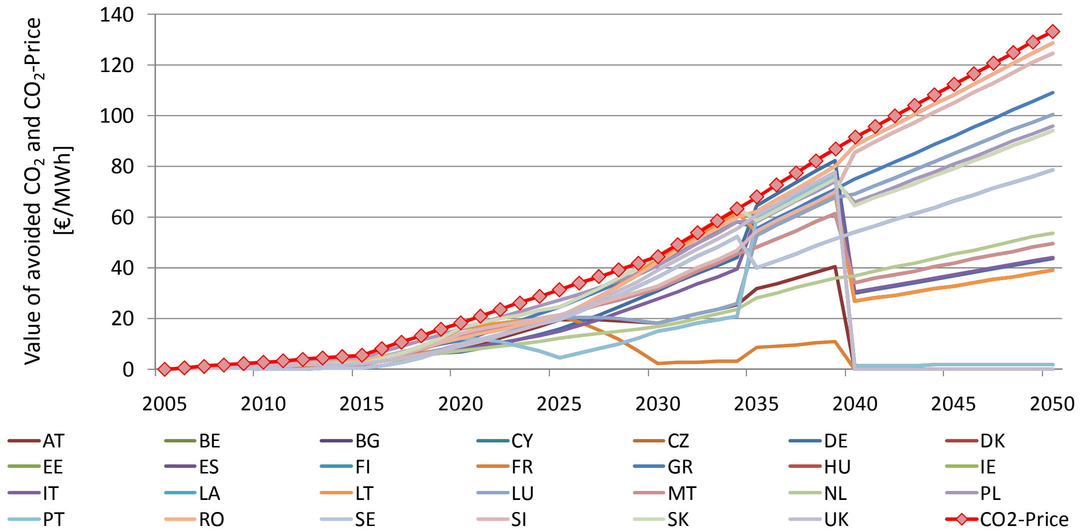
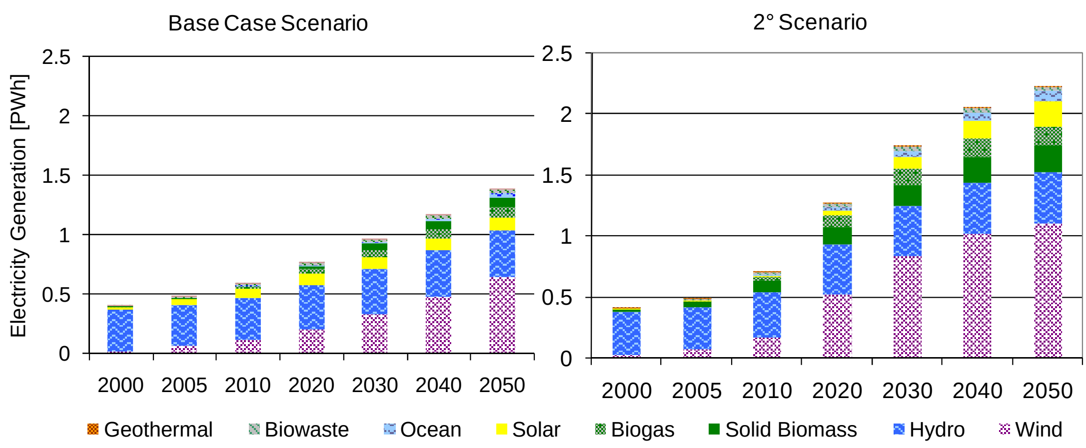


Figure 10-1: Value of avoided CO_2 and reference CO_2 price

Electricity demand data forecasted by the different bottom-up models calculating sectoral electricity demand (see Chapter 6 - 9) have been used by the PowerAce-ResInvest model in this chapter.

10.3.2 Results for electricity generation by renewables in Europe – Base Case Scenario and 2° Scenario 2000 to 2050

Given the implementation of technology-specific support policies and the support resulting from the CO_2 value, we expect an increase in renewable based electricity generation from 488 TWh to 2,222 TWh by 2050 under 2° Scenario assumptions (see Figure 10-2). At a first glance, the total growth rate of roughly 350 % indicates a substantial growth of the use of RES, but taking into account the long-term horizon of 45 years, the annual growth on average of 3.4 % shows that the increase still remains at a reasonable level. Comparing the evolution of renewable technologies in both scenarios, it becomes clear that total RES-E generation in the 2° Scenario exceeds total renewable electricity production in the Base Case by 60 % by mid-century.



Source: PowerACE-ResInvest, own calculations

Figure 10-2: Electricity generation based on renewables, EU27 and Base Case Scenario (left figure) and 2° Scenario (right figure), 2000 to 2050

The deployment of RES-E technologies appears to accelerate earlier in the 2° Scenario than compared to the Base Case. Thus, total electricity production from wind by 2020 is 150 % higher than in the Base Case. Later on wind energy development accelerates also in the Base Case Scenario (see Table 10-3). Assuming 2° Scenario conditions, wind energy takes over the dominant role of hydropower in 2017 and contributes almost half of total renewable electricity generation (49 %) by 2050. Since the potential for hydropower has nearly been fully exploited, this technology only shows moderate growth until 2050 in both scenarios. In contrast, wind energy shows a substantial development in particular in the 2° Scenario.

Table 10-3: Overview of electricity generation based on renewable energies, in TWh, EU27 total, Base Case Scenario and 2° Scenario, 2005 – 2050

Electricity generation [TWh]	Historic	Base Case Scenario		2° Scenario		Changes (2° against Base Case Scenario)	
	2005	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
Wind	71	206	645	516	1,093	+150%	+70%
Hydro	336	374	396	405	420	+8%	+6%
Solid Biomass	49	93	103	144	224	+56%	+117%
Biogas	15	44	93	103	157	+131%	+70%
Solar	1	25	78	36	203	+44%	+159%
Ocean	0	3	36	30	85	+860%	+137%
Biowaste	10	25	29	27	30	+8%	+4%
Geothermal	5	8	8	9	9	+14%	+18%
RES-E total	**488**	**779**	**1,388**	**1,270**	**2,222**	**+63%**	**+60%**

Source: PowerACE-ResInvest, own calculations

According to our modelling results, 87 % of total wind energy generation comes from onshore wind power plants assuming 2° Scenario conditions. The share of biomass technologies including solid biomass, biowaste and biogas in total renewables will increase from 15 % in 2005 to 19 % in 2050, allowing a growth of 338 TWh from 74 TWh annual electricity production in 2005 to 411 TWh by 2050, given that enhanced climate policies are active (see Table 10-3). In the 2° Scenario electricity generation from solar energy increases from 1 TWh in 2005 to 203 TWh by 2050. Thereby, 67 % of total solar electricity generation in 2050 is provided on the basis of photovoltaics technology. The remaining 33 % is generated by means of solar thermal power plants in southern Europe.

Table 10-4: Electricity generation based on renewable energies, in TWh, EU27, Base Case Scenario and 2° Scenario, 2005 to 2050

Electricity generation [TWh]	Historic	Base Case Scenario		2° Scenario		Changes (2° against Base Case Scenario)	
	2005	2020	2050	2020	2050	2020	2050
Austria	40	47	53	56	57	19%	7%
Belgium	2	8	18	11	21	43%	18%
Bulgaria	4	7	9	12	26	59%	184%
Cyprus	0	0	1	1	2	230%	374%
Czech Republic	3	9	23	16	43	85%	88%
Germany	62	106	135	153	298	44%	121%
Denmark	10	21	32	27	32	30%	0%
Estonia	0	2	8	5	8	159%	7%
Spain	58	92	138	216	272	134%	97%
Finland	23	28	32	35	64	28%	96%
France	69	98	217	133	357	35%	64%
Greece	7	15	32	27	51	74%	60%
Hungary	2	4	7	10	17	127%	133%
Ireland	2	8	22	20	24	147%	6%
Italy	48	80	121	118	184	48%	53%
Latvia	3	4	9	7	8	66%	-10%
Lithuania	0	1	4	6	10	336%	140%
Luxembourg	0	0	1	1	1	186%	65%
Malta	0	0	0	0	0	443%	156%
Netherlands	8	12	37	30	56	144%	52%
Poland	4	15	36	37	112	155%	213%
Portugal	15	28	40	55	55	96%	38%
Romania	20	25	34	38	49	53%	47%
Sweden	82	91	121	110	149	21%	23%
Slovenia	4	9	9	10	12	10%	28%
Slovakia	5	6	8	10	17	53%	116%
United Kingdom	17	61	243	127	298	108%	23%
EU 27	**488**	**779**	**1,388**	**1,270**	**2,222**	**+63%**	**+60%**

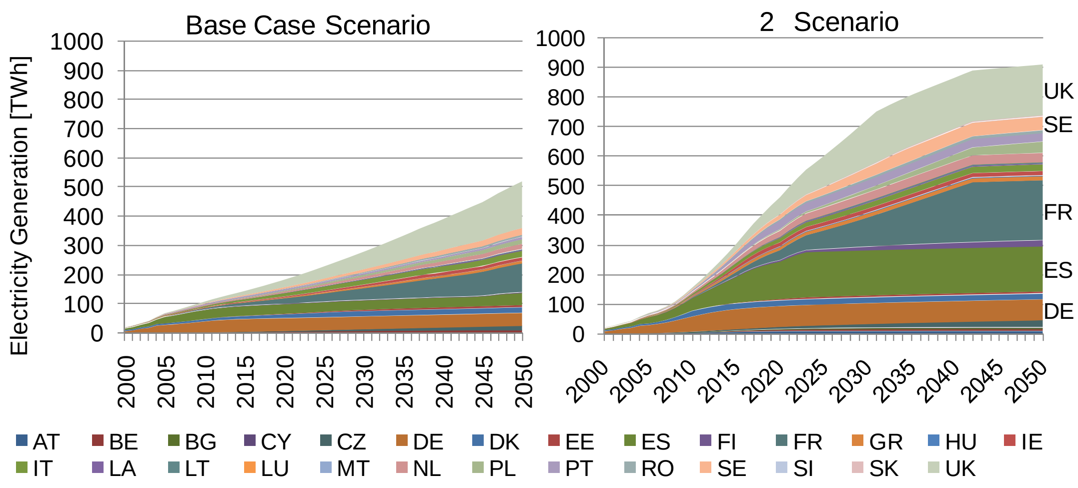
Source: PowerAce-ResInvest, own calculations

Looking at the countries' contribution to European RES-E production, the large European countries make the most substantial contributions to the entire EU electricity supply based on renewables. Thus, most of the total renewable electricity generation in EU27 will be generated in France (16 % of total renewable electricity generation in the EU), the United Kingdom and Germany (13 % each), Spain (12%) and Italy (8 %) followed by Sweden (8 %) and Poland (7 %).

The following sections comment briefly on the development of each renewable energy generating electricity in terms of its development for each Member State and the EU27.

10.3.2.1 Wind onshore

The increase in wind electricity generation on land under the 2° Scenario is considerable stronger than in the Base Case and the Reference Scenario level (see Figure 10-3). Total annual electricity generation from wind onshore plants amounts to 912 TWh by 2050, exceeding the wind electricity generation in the Reference and in the Base Case Scenario by 75 %. This development shows that the implementation of adequate support policies for wind energy allows for considerably stronger market development. However, some countries with a high initial share of wind energy in the overall portfolio, such as Germany and Spain, show a saturation of the market. In Germany the construction of wind power plants on land appears to reach its potential limits, whereas in Spain the additional construction of wind power plants is not hampered by potential limitations, but rather by a too high share of fluctuating renewable energy sources in the electricity system. In contrast, other countries like France and the UK with a low initial share of wind power in their technology portfolio, have a substantial potential for the use of wind onshore power plants and owing to favourable policy measures they will catch up and may become the largest producers of wind power by the year 2050. Depending on the wind regime of the site, average electricity generation costs of the plants installed in the five largest wind power countries (UK, FR, ES, SE, DE) during the time horizon from 2005 to 2050 range from 39 €/MWh in the UK to 72 €/MWh in Germany. Comparing the electricity generation costs with a range of electricity prices between 47 €/MWh in France and 87 €/MWh in Germany, it becomes clear that wind electricity generation costs will be competitive with conventional conversion technologies by 2050. In general, the development of the average electricity generation costs of wind onshore electricity is affected by two opposing effects. First, technological learning involves decreasing investments and electricity generation costs and second, the depletion of areas with good wind resources implies rising electricity generation costs.

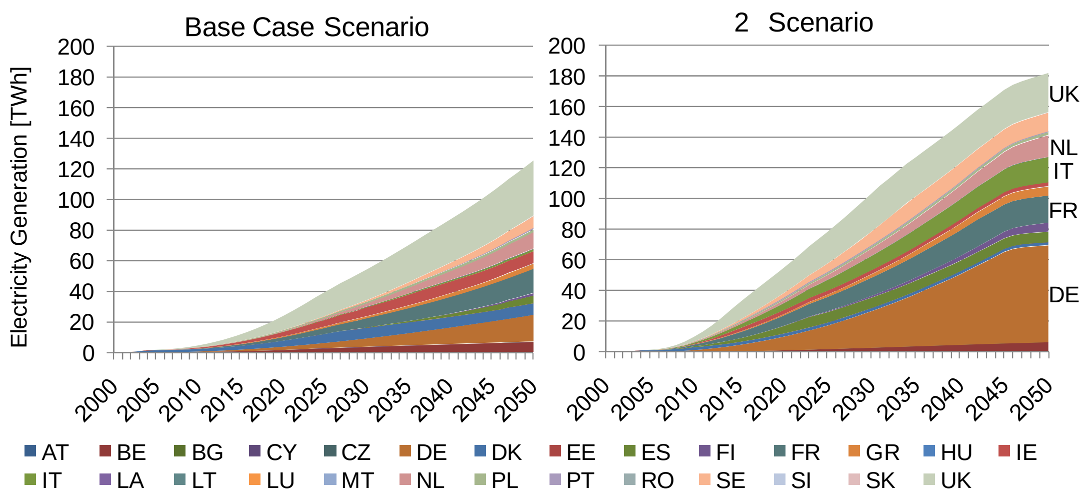


Source: PowerACE-ResInvest, own calculations

Figure 10-3: Electricity generation based on wind onshore, EU27, Base Case and 2° Scenario, 2000 to 2050

10.3.2.2 Wind offshore

Due to existing problems with wind power installations on sea (i.e. technical problems concerning foundation, grid integration, problems with obtaining permits), current wind offshore development lags somewhat behind expectations. The future progress of this technology therefore depends on whether and when the currently existing technical and administrative barriers can or may be overcome. As there is clearly less experience with commercial applications of wind offshore plants than with wind power plants on land, the modelling of the future development of this technology involves higher uncertainties. One possible pathway of an enhanced offshore development under the 2° Scenario is shown in Figure 10-4. Assuming the reinforced implementation of policy support measures, total wind offshore electricity generation by 2050 exceeds the corresponding generation in the Base Case Scenario by 45 % and amounts to 182 TWh in absolute terms. However, Figure 10-4 shows a moderate development of wind offshore plants up to 2010 and continues with stronger growth from then on. Owing to the existing technical potentials and the policy support offered in particular countries, Germany, the United Kingdom and France will be the largest contributors of wind offshore energy in mid-century, producing 63 TWh (DE), 25 TWh (UK) and 18 TWh (FR) of electricity by 2050.

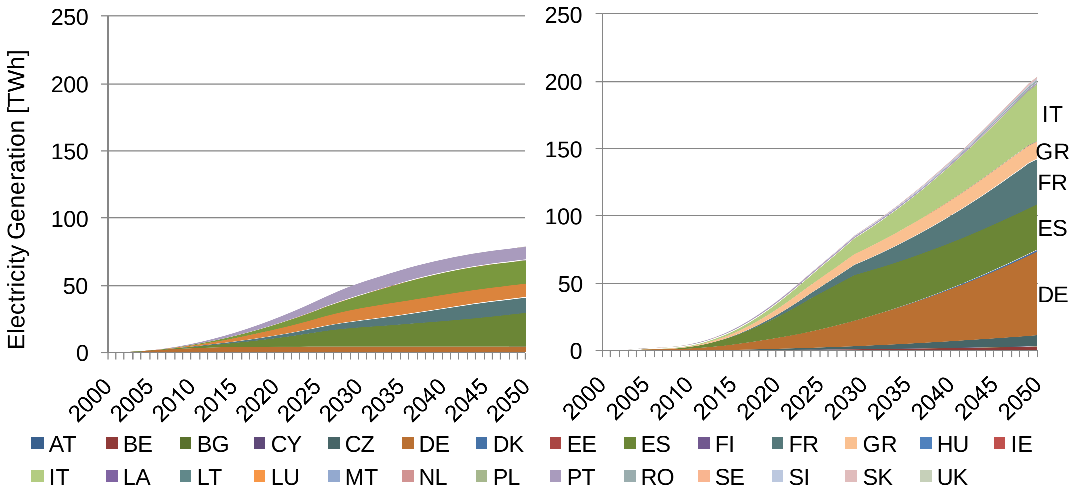


Source: PowerACE-ResInvest, own calculations

Figure 10-4: Electricity generation based on wind offshore, EU27, Base Case and 2° Scenario, 2000 to 2050

10.3.2.3 Solar energy

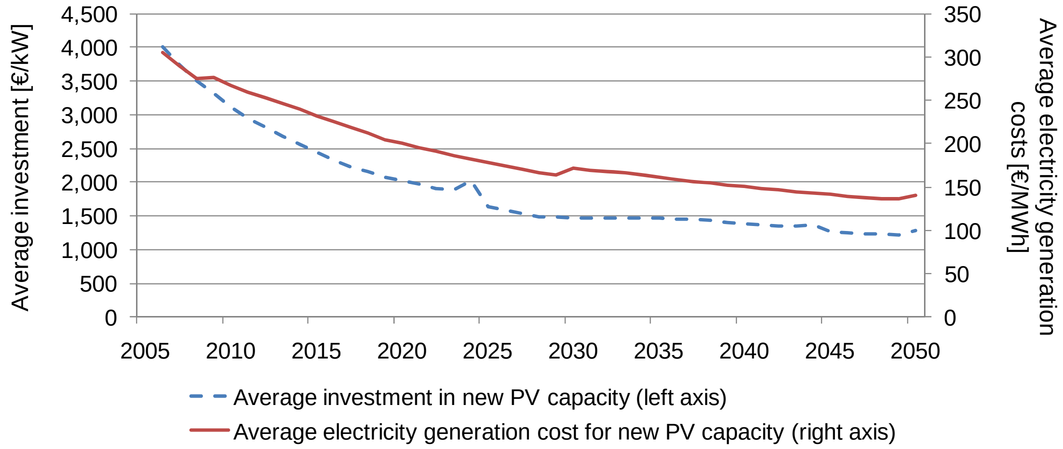
Whereas PV electricity may theoretically be produced in all European countries, solar thermal electricity generation needs direct solar irradiation (without clouds) and electricity generation is only economical in southern European countries. If there is sufficient direct solar irradiation to generate electricity using solar thermal conversion technologies, generation costs are considerably below those of PV, at least for the next two decades. Even so, grid-connected PV technology already shows higher market diffusion rates than solar thermal electricity within Europe at present and accounted for 3.3 GW of installed capacity (EurObserv'ER 2007). Germany is the country with most installed solar energy capacity in terms of photovoltaics, delivering more than 85 % of the total PV electricity generated within Europe. Comparing the potential development of solar energy under the assumption of enhanced climate policies with the Base Case Scenario, we observe a strong boost in the use of solar energy for electricity production. Whereas electricity production from solar energy achieved 78 TWh by 2050 under Base Case Scenario assumptions, the corresponding value in the 2° Scenario amounts to 203 TWh and consequently exceeds electricity generation with wind power plants on sea. 77 % of the entire solar electricity is thereby produced based on photovoltaics. Besides the southern European countries Italy, Spain and France, Germany contributes a large share of total solar electricity generation as a result of favourable support conditions for photovoltaics (Figure 10-5).



Source: PowerACE-ResInvest, own calculations

Figure 10-5: Electricity generation based on solar energy, EU27, Base Case and 2° Scenario, 2000 to 2050

Economic considerations rather than the available potential represent the main limiting factor to the development of solar energy. One should also consider that the future development of solar energy may vary from the pathways shown in the ADAM scenarios, depending particularly on the development of the corresponding electricity generation costs. Our modelling results indicate that the strong market development of Solar PV plants involves a strong reduction of PV investment and the corresponding electricity generation costs as a result of technological learning effects, assuming a learning rate of 20 % (see Figure 10-6). Thus, average investment in newly installed plants decreases from 4,000 €/kW on average in 2005 to one third of the initial value or 1,285 €/kW by 2050. This reduction in investment leads to a reduction of average electricity generation costs from slightly above 300 €/kWh to 140 €/MWh by 2050.

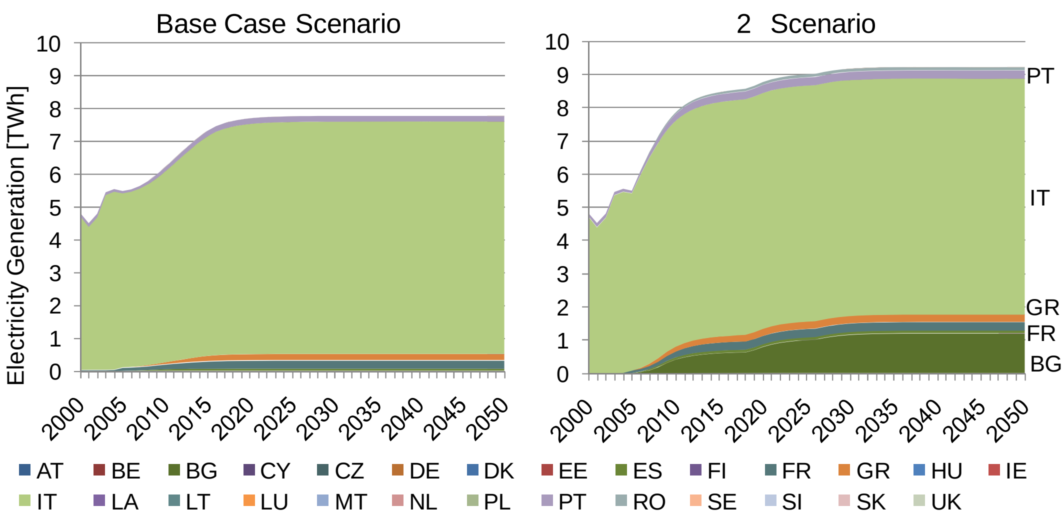


Source: PowerACE-ResInvest, own calculations

Figure 10-6: Financial characteristics of additionally installed Solar PV plants, EU27, 2° Scenario, 2000 to 2050

10.3.2.4 Geothermal energy

The development of high-temperature geothermal energy systems for electricity generation in the 2° Scenario is slightly stronger than in the Base Case Scenario. Indeed, geothermal electricity is able to make only a marginal contribution to the entire renewable electricity supply, amounting to an annual production of 9 TWh (7 TWh in the Base Case Scenario) by 2050 (see Figure 10-7). Since the technical potentials for high-temperature hydrothermal geothermal energy systems (electricity generation) are restricted within Europe, a slight increase of geothermal electricity production is expected for Italy. Hot-dry-rock systems are not included, since it is not yet commercially proven and we do not expect any substantial development of this technology, due to existing technical problems.

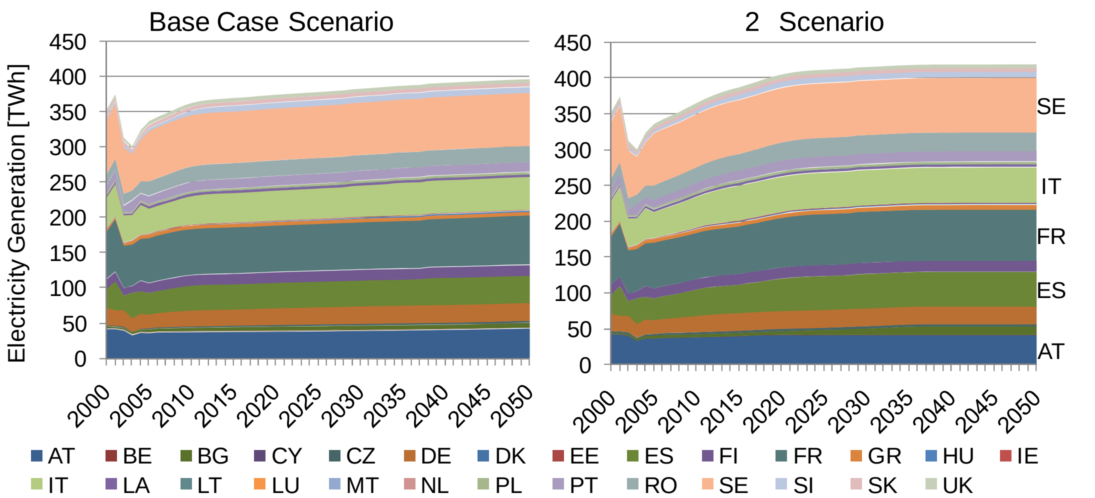


Source: PowerACE-ResInvest, own calculations

Figure 10-7: Electricity generation based on hydrothermal geothermal energy, EU27, Base Case and 2° Scenario, 2000 to 2050

10.3.2.5 Hydroenergy

Since most of the available hydropower potential is already being exploited, the use of hydroenergy remains at a rather constant level and does not show considerable changes when the 2° Scenario is compared with the Base Case Scenario. There is only a slight increase up to 2050, in particular including small hydropower plants with a capacity size of up to 10 MW (see Figure 10-8). Whilst our modelling calculations indicate an annual electricity production based on hydropower of 420 TWh in the 2° Scenario, 396 TWh are produced under Base Case Scenario assumptions. It must be noted that annual hydropower production may vary considerably according to the precipitation patterns, as can be seen in the historic development between 2000 and 2005. The annual variations have not been modelled with PowerACE-ResInvest. Inter-annual variations are considered within EuroMM (see Reiter et al. 2009).

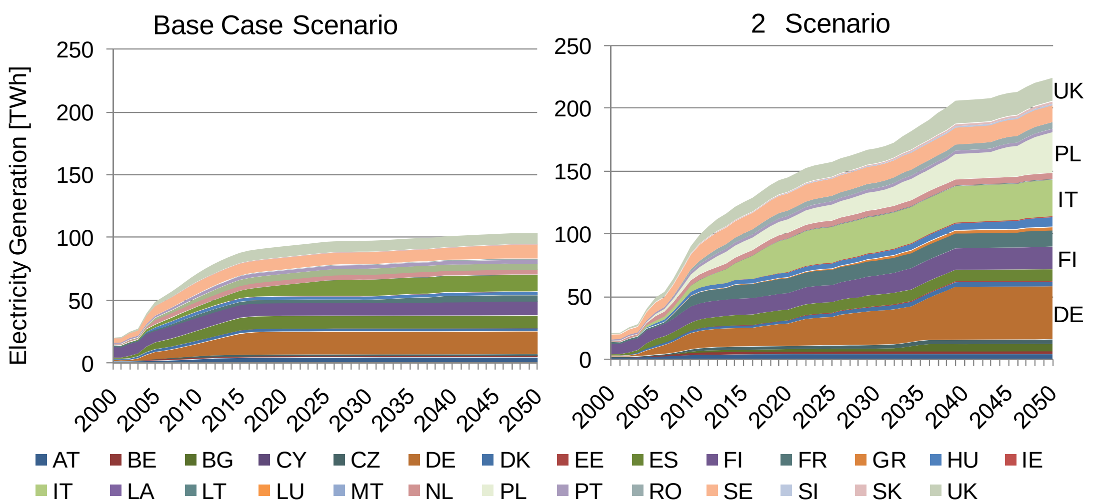


Source: PowerACE-ResInvest, own calculations

Figure 10-8: Electricity generation based on hydroenergy, EU27, Baseline and 2° Scenario, 2000 to 2050

10.3.2.6 Solid biomass

According to modelling results, total electricity generation from biomass by 2050 doubles, reaching an annual electricity production of 224 TWh when comparing the 2° Scenario to the Base Case Scenario (see Figure 10-9). About 54 % of the electricity generated in 2050 is expected to be produced in CHP plants.



Source: PowerACE-ResInvest, Own calculations

Figure 10-9: Electricity generation based on biomass, EU27, Base Case and 2° Scenario, 2000 to 2050

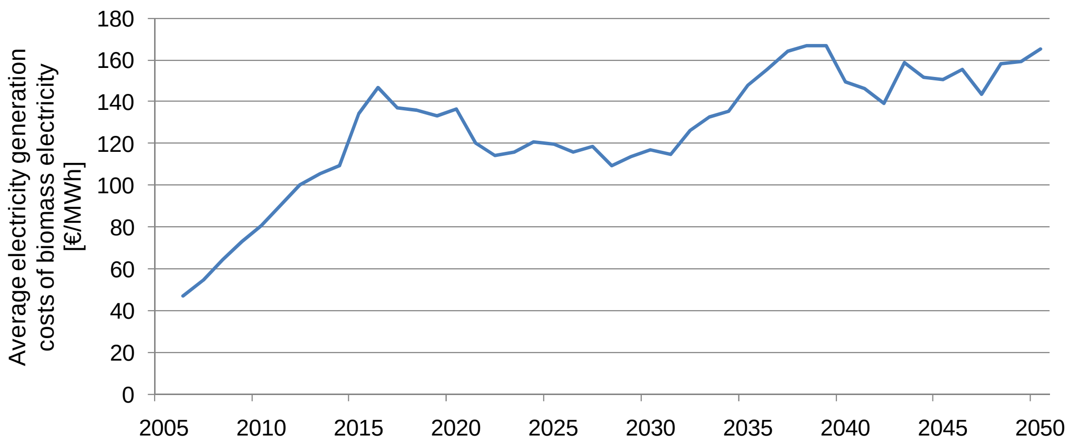
Whilst most of the biomass electricity generation in the Base Case Scenario comes from northern European (Sweden, Finland) countries with a large wood and paper industry, the increase in the use of biomass in the 2° Scenario is additionally based on other biomass feedstock such as agricultural products and forest products (see Table 10-5). In the Base Case Scenario, the use of biomass for electricity and CHP generation is clearly dominated by cheap residual biomass. In contrast, primary energy use in the 2 ° Scenario relies additionally on more expensive feedstock, such as agricultural products and forest products as a consequence of reinforced policy efforts. Thus, primary energy input of agricultural products rises from 47 PJ in the Base Case Scenario to roughly 800 PJ. The corresponding input from forest products is increased by 160 % from 261 PJ to 678 PJ.

Table 10-5: Primary energy use of solid biomass for electricity and CHP generation

Primary Energy Input [PJ]	**Historic**	**Base Case Scenario**		**2° Scenario**		**Changes (2° against Base Case Scenario)**	
	2005	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
Agricultural products	25	34	47	239	797	+599%	+1,582%
Agricultural residues	25	284	327	455	634	+61%	+94%
Forest products	172	198	261	300	678	+52%	+160%
Forest residues	151	429	514	585	643	+36%	+25%
Black liquor	138	215	248	267	289	+24%	+17%
Solid biomass	**511**	**1,160**	**1,397**	**1,846**	**3,041**	**+59%**	**+118%**

Source: PowerACE-ResInvest, own calculations

Electricity generation costs of biomass technologies may vary considerably, depending on the conversion technology and the biomass feedstock used. Average costs of additionally installed capacity, as shown in Figure 10-10, show an increasing trend as no significant technological progress is expected for conversion technologies that use solid biomass. In the beginning of the modelling period, low cost potentials such as co-firing biomass to conventional fuels are exploited first in combination with comparatively cheap residual biomass feedstock. This fact explains the comparatively low electricity generation costs of 50 to 80 €/MWh up to 2011. Later on, more cost-intensive technologies and biomass resources have to be used and average electricity generation costs rise before they peak at approximately 160 €/MWh by mid-century.

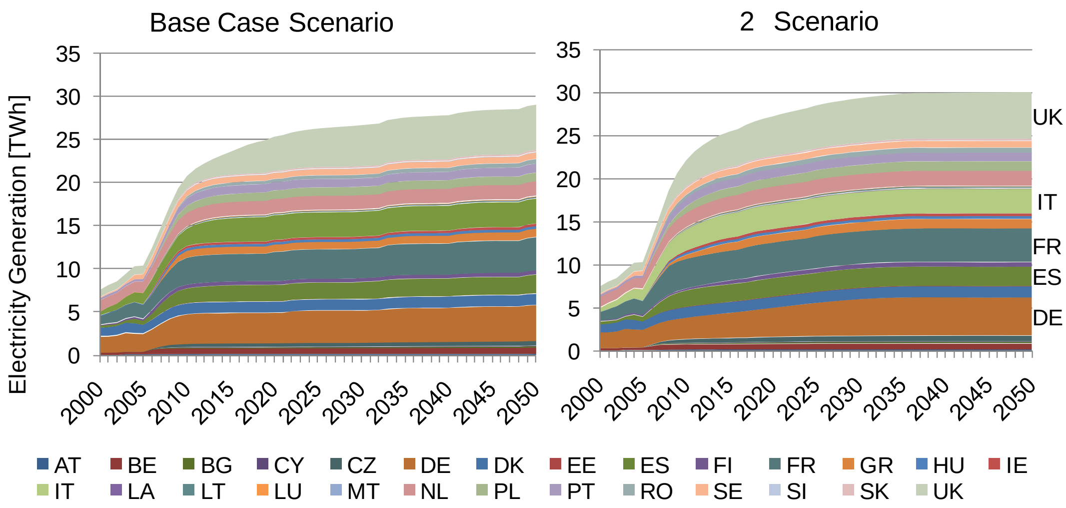


Source: PowerACE-ResInvest, own calculations

Figure 10-10: Average electricity generation costs of additionally installed biomass technologies, EU27, 2° Scenario, 2000 to 2050

10.3.2.7 Biowaste

The evolution of biowaste according the PowerACE 2° Scenario is characterised by considerable growth until 2010 and then slows down, since exploitation already approaches the potential limits (see Figure 10-11). It is for this reason that the entire electricity production based on biowaste in the 2° Scenario is only marginally above the level (+3.7 %) achieved under Base Case Scenario assumptions and reaches 30 TWh by 2050.

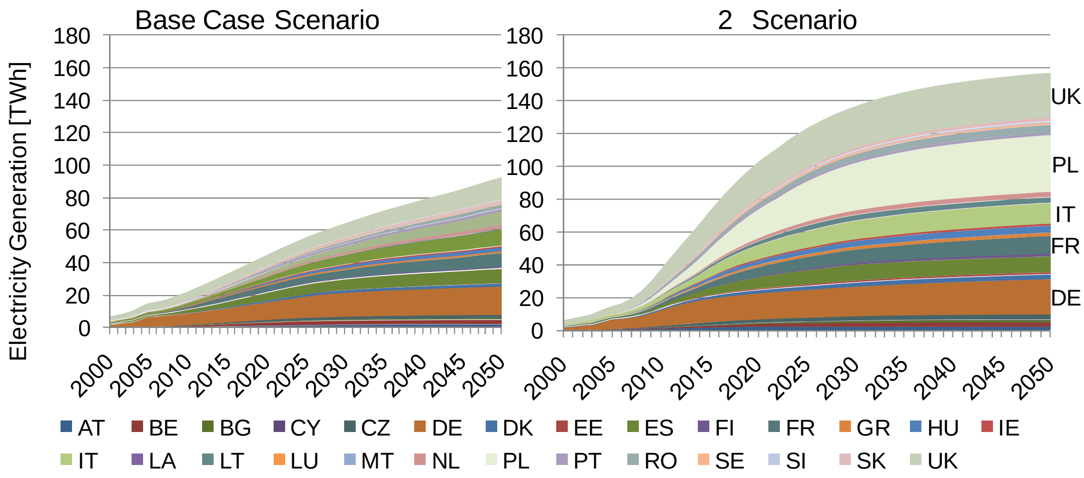


Source: PowerACE-ResInvest, own calculations

Figure 10-11: Electricity generation based on biowaste, EU27, 2° Scenario, 2000 to 2050

10.3.2.8 Biogas

According to modelling results, we expect electricity production based on biogas to increase up to 157 TWh by 2050, assuming the implementation of support policies in the 2° Scenario (see Figure 10-12). This corresponds to a rise by 70 % compared to the development of biogas conversion technologies under Base Case conditions.



Source: PowerACE-ResInvest, own calculations

Figure 10-12: Electricity generation based on biogas (agricultural biogas, landfill gas and sewage gas), Base Case and 2° Case Scenario, 2000 to 2050

Most of the growth in the use of biogas for electricity production can be attributed to a strong development of agricultural biogas resulting from agricultural products (cereals, oil crops, grass, maize, perennial grasses, etc.) and agricultural residues (manure and crop residues). In the 2° Scenario about 77 % of the electricity produced using biogas in 2050 corresponds to the use of agricultural biogas (see Table 10-6). 18 % of the electricity production from biogas in 2050 is based on the use of landfill gas, with the rest attributed to sewage gas.

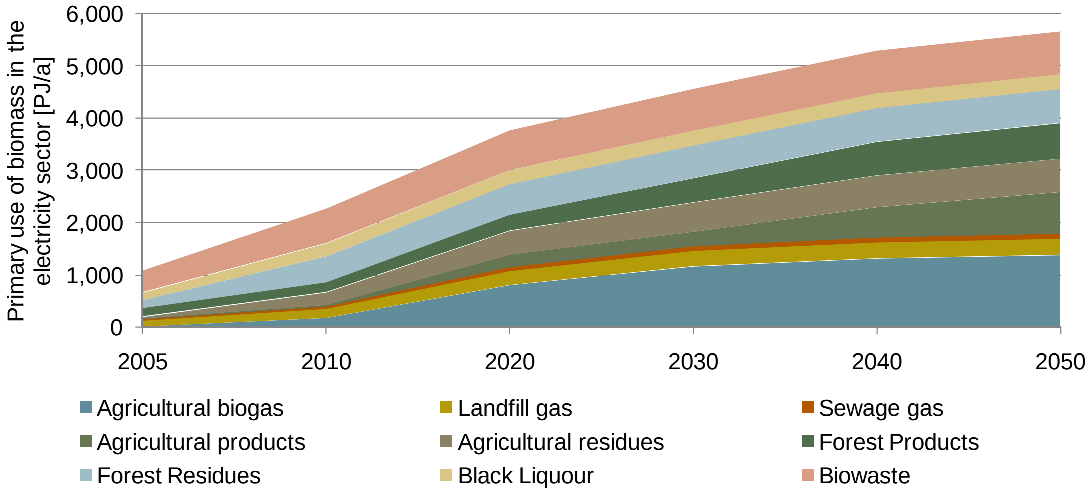
Table 10-6: Primary energy use of biogas types for electricity and CHP generation

Primary Energy Input [PJ]	Historic	Base Case Scenario		2° Scenario		Changes (2° against Base Case Scenario)	
	2005	2020	2050	2020	2050	2020	2050
Agricultural biogas	0	167	605	794	1,373	+376%	+127%
Landfill gas	113	240	327	272	318	+13%	-3%
Sewage gas	35	65	84	85	102	+30%	+21%
Biogas	148	473	1,017	1,151	1,793	143%	76%

Source: PowerACE-ResInvest, own calculations

10.3.2.9 Primary use of all biomass types

In general, total use of primary biomass in the 2° Scenario by 2050 shows an increase by 78 % as compared to the Base Case and achieves 6,652 PJ/year. In contrast to the primary use of biomass feedstock in the Base Case Scenario, the development in the 2° Scenario is characterised by a stronger utilisation of agricultural biogas, agricultural products and forest products. Of course, this development involves considerably higher generation costs owing to the comparatively high feedstock prices of wood products (particularly of chips) and of agricultural products (see Figure 10-13).



Source: PowerACE-ResInvest, own calculations

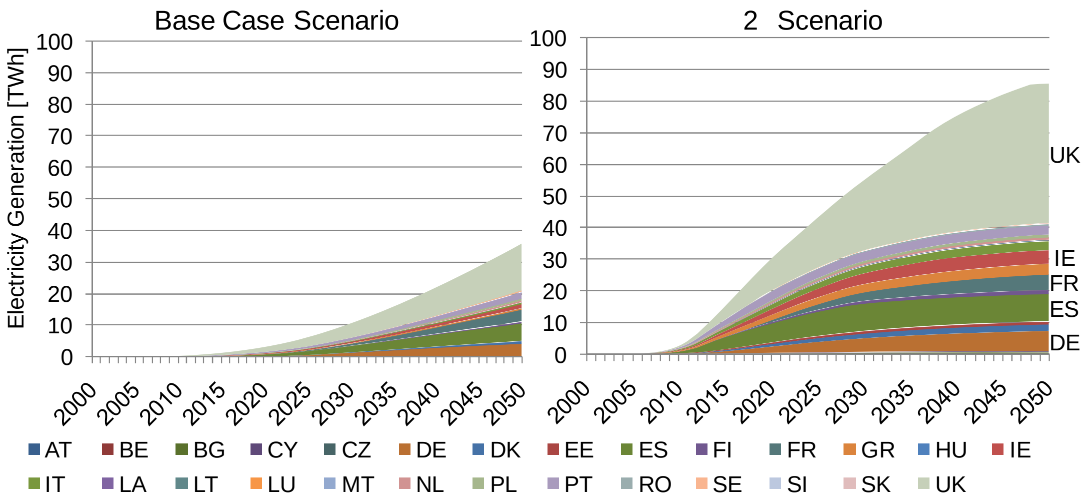
Figure 10-13: Primary use of biomass in the electricity sector according to the corresponding biomass input[19]

One should consider that the deployment of residual biomass resources should still be preferable to the use of biomass products that can be used for non-energy purposes (e.g food production, material use). As the biomass potentials used within this modelling exercise have been estimated considering competition for biomass feedstock and environmental aspects (see European Environment Agency 2006), the pathway shown does not jeopardise food supply or environmental damages associated with a pronounced cultivation of biomass crops for energy purposes. The contribution of biowaste remains at a high level and experiences slight growth.

19 As data regarding the historical use of biomass for electricity generation, figures were estimated using known shares of biomass primary composition as described in EurObserver (2007).

10.3.2.10 Ocean energy

As only few practical experiences exist with wave and tide technologies, their potential future development is highly uncertain and depends to a large extent on the technological development of the respective technologies. The first commercial wave power plant with a size of 2.25 MW has recently been implemented in Portugal near the city of Porto (September 2008). Assuming positive technological progress and the implementation of strong policy support up to 2050 in the 2° Scenario, wave and tidal energy development could provide some 85 TWh of electricity per year (see Figure 10-14). Due to its large potential, the UK is expected to provide more than half of the total electricity from the sea.

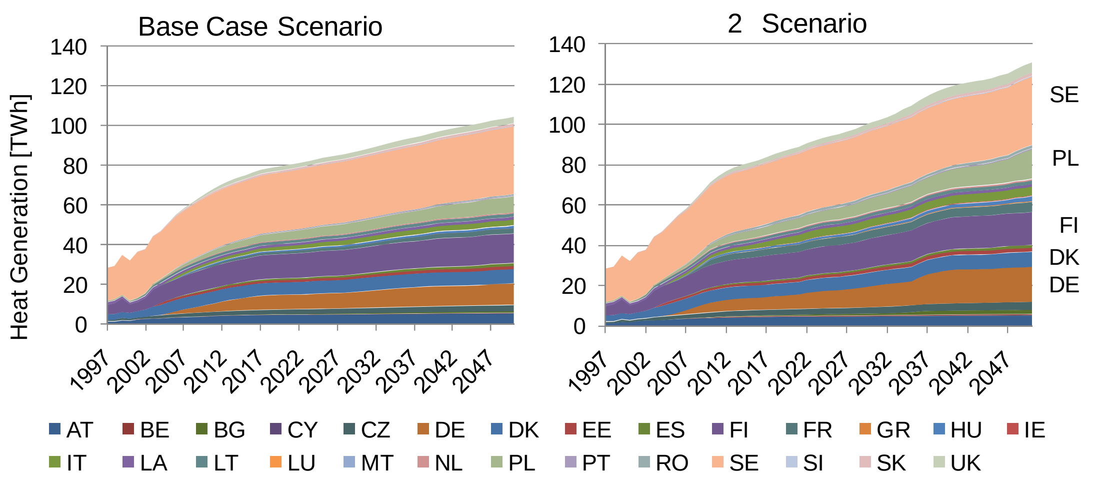


Source: PowerACE-ResInvest, own calculations

Figure 10-14: Electricity generation based on wave and tidal energy, EU27, Base Case and 2° Scenario, 2000 to 2050

10.3.2.11 The use of biomass in district heating plants and CHP-plants

In particular Northern European countries with a huge wood and paper industry such as Sweden, Finland and Denmark are supposed to be the leading countries within Europe with regard to heat generation from district heating plants and CHP-plants at present as well as in the year 2050. The projections result in an increase from some 35 PJ in 2000 to almost 130 PJ in 2050 in the 2° Scenario (see Figure 10-15). This value corresponds to a slight increase of 18 % compared to the development of district heating plants in the Base Case, which is due to an increased heat output from CHP-plants.



Source: PowerACE-ResInvest, own calculations

Figure 10-15: Heat generation based on biomass grid-connected systems, EU27, Base Case and 2° Scenario, 2000 to 2050

10.3.3 Mitigation costs in the renewables sector

The increased use in the 2° Scenario involves additional investments in renewable conversion technologies. Cumulated investments in renewables in the electricity secter amount to € 820 billion in the Base Case Scenario and to € 1,545 billion in the 2° Scenario (see Figure 10-16)[20]. This means that the assumed achievement of the 2° target requires an additional investment of € 724 Billion compared to the Base Case. It should thereby be considered that this investment replaces investment in conventional conversion technologies (see Chapter 11). Owing to the strong development of wind energy, the predominant part of the investment is dedicated to this technology, amounting to € 710 billion up to 2050 in the 2° Scenario. At the same time, € 251 billion are expected to be invested in solar energy technologies, € 115 billion are spent on biogas plants and € 110 billion on conversion plants that use solid biomass[21]. Investment in hydro energy remains nearly constant, as it results predominantly from the refurbishment of existing plants than from the construction of new hydro power capacity.

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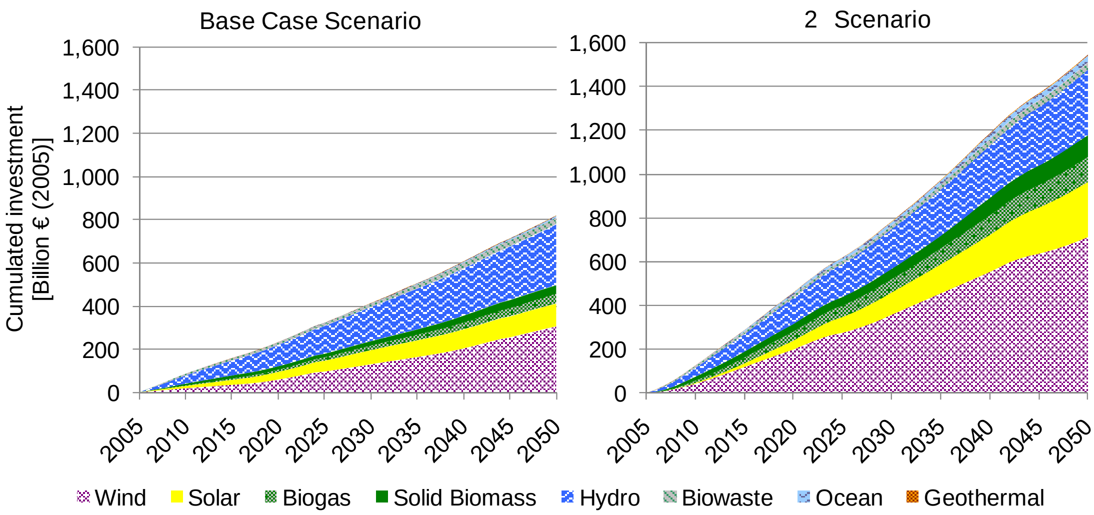
20 Cumulated investment includes investment in the capacity of RES installations that have ended their life cycle and need to be replaced during the modelling horizon.

21 Cumulated investments into solar energy in the EuroMM-model result to be considerably higher, as lower learning rates for Photovoltaics have been assumed (see Chapter 11).

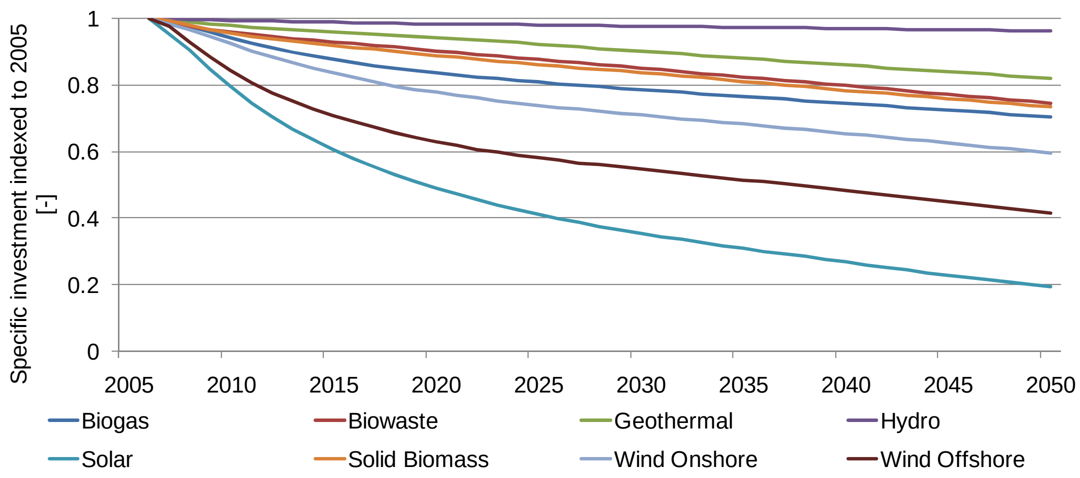
The cumulated investment into district heating plants in the 2° Scenario amounts to € 9 billion during the considered modelling horizon and remains unchanged compared to the investment undertaken under Base Case conditions.



Source: PowerACE-ResInvest, own calculations

Figure 10-16: Cumulated investment based on renewables, EU27, Comparison of 2° Scenario (right figure) with Base Case Scenario (left figure), 2000 to 2050

According to modelling results, the development of renewables technologies accompanies technological development, that results in a reduction of specific investment in Solar PV technologies to 20 %, when comparing the year 2050 with the default value in the year 2005 (see Figure 10-17). Significant reductions may take place for wind offshore plants achieving roughly 40 % of the initial investment value by 2050. With regard to biomass technologies and hydropower plants, no significant progress in terms of investment reductions is anticipated,, as most of these represent rather mature and experienced technologies.



Source: PowerACE-ResInvest, own calculations

Figure 10-17: Specific investment indexed to 2005, 2° Scenario, 2000 to 2050

10.4 Conclusions on policies to achieve changes in the renewables sector

Increasing the share of renewable energy sources in the electricity mix was identified as a crucial factor which could make a substantial contribution to mitigating climate change. Because many RET-options are not yet cost-effective, financial support is required to stimulate the growth of renewable energy conversion technologies. This financial support can be provided by the **continuous** and **enhanced application** of various climate policies. The results of our analysis indicate that only applying a European emission trading scheme does not provide sufficient incentives to make most RET-options competitive with other conversion technologies at least during the next two decades.

Therefore, **sectoral policy measures** adapted to the specific requirements of RET, such as feed-in tariff systems, should be applied besides sector-uniform cap and trade policies in order to trigger a sufficiently rapid diffusion of RET. Merely deploying low-cost electricity generation technologies such as wind onshore will not be sufficient to meet the climate target of a 2 degree increase by 2050. Instead, it is necessary to **exploit** the **full range of RET**. The sectoral policy measures may also stimulate the market development of cost-intensive RET, needed to meet the climate target, and encourage future **cost reductions** as a result of technological learning and economies of scale.

Technology specification of support and **investment security** were found to be the core elements of policy measures applied in the renewables sector. The technology-specific distinction of support levels applies to the heterogeneous economic characteristics of various RET-options. Thus, a policy measure should be based on a financial support level which is designed such that RET-projects become profitable without overcompensating investors. This policy is capable of stimulating investments without provoking unnecessary windfall profits and thus incurring excessive support costs for society.

Besides policies to enhance the market development of already quite mature technologies, **emerging technologies** that still need to make considerable technological progress should also be supported by **research and development (R&D) policies**. Using technology options in addition to those considered within the modelling runs may make an important contribution to achieving the ambitious climate targets, in particular if the policies assumed to be active under the 2° Scenario cannot be realised in reality for political reasons. Owing to the fact that the policy assumptions in the 2° Scenario reflect very ambitious climate targets, this may be likely to happen. Likewise, the option of **importing green electricity** from outside the EU should be considered as an option to combat climate change, although it is not represented within the model. Importing concentrating solar power (CSP) from North Africa represents a promising alternative. At present there are already private investors planning to build CSP-plants in North Africa and to export the electricity to Europe[22].

22 See also http://www.desertec.org/.

11 Conversion sector in Europe

11.1 Target of analysis

The target of the analysis is to identify technology options in the conversion sector for achieving stringent climate change mitigation targets in Europe, including possible bottlenecks between the energy demand side and the energy conversion sector which may undermine mitigation efforts. To realise this objective, the analysis models the European Energy conversion sector using EuroMM, which brings together the outputs of a set of models describing several final energy demand sectors and the renewable electricity generation sector, together with a detailed technological representation of the conventional conversion sector. In this report we focus on an analysis of climate change mitigation scenarios with the two driving boundaries of 400 and 450 ppm CO_2-eq concentrations allowed over the long term.

11.2 Policies / Technologies / Assumptions and model rationale / limits for EuroMM

In the analysis for the mitigation scenario we base our assumptions for final energy demands on the results from the other bottom up models involved in the ADAM-M1 team. On the energy conversion side we use the detailed representation of electricity generation technologies in EuroMM, including fossil fuel based technologies with carbon capture and sequestration, nuclear technologies as well as renewable electricity technologies which are further described in section 10. EuroMM also covers fuel refining technologies, biofuel production technologies as well as hydrogen production facilities, which supply fuels to transport and other sectors based on (Guel, 2008). A range of parameters are specified to define the characteristics of each technology option in the model, including investment costs, and fixed and variable operation and maintenance costs. In addition, parameters defining the efficiency of each technology are specified, along with annual and seasonal availability factors during which production is allowed. EuroMM is used to determine the least-cost combination of technology and fuel options to meet a given set of energy demands subject to certain technical and policy constraints. The model is calibrated to the statistical data of the year 2005 (Eurostat, 2005). More information about model details can be found in (Reiter U. and Held A., 2009) and in the model description as part of deliverable M1.1 (Jochem et al., 2007).

On the policy side we assume that the implemented policies on country level regarding nuclear electricity generation which were in place in 2005 are continued in the future. This means nuclear energy is phased out in Germany and Sweden. In countries such as Italy and Austria, new investments in nuclear power generation only appear after 2025. Policies on the use and implementation of renewable energy are according to the data of PowerAce-ResInvest. Data on fossil fuel prices and emission targets were obtained from Mima S. and Criqui P. (see section 4).

One of the limiting parameters in EuroMM is the resolution of time[23] for the analysis of interactions between non-dispatchable electricity sources and baseline production and demand. Due to the high share of fluctuating renewable power in the electricity sector in mitigation scenarios (shown in section 11.3.1) it becomes more important to show solutions for its reliable integration in the network. A higher time resolution would be advantagous to prove the feasibilty of our presented results.

11.3 Results of scenarios

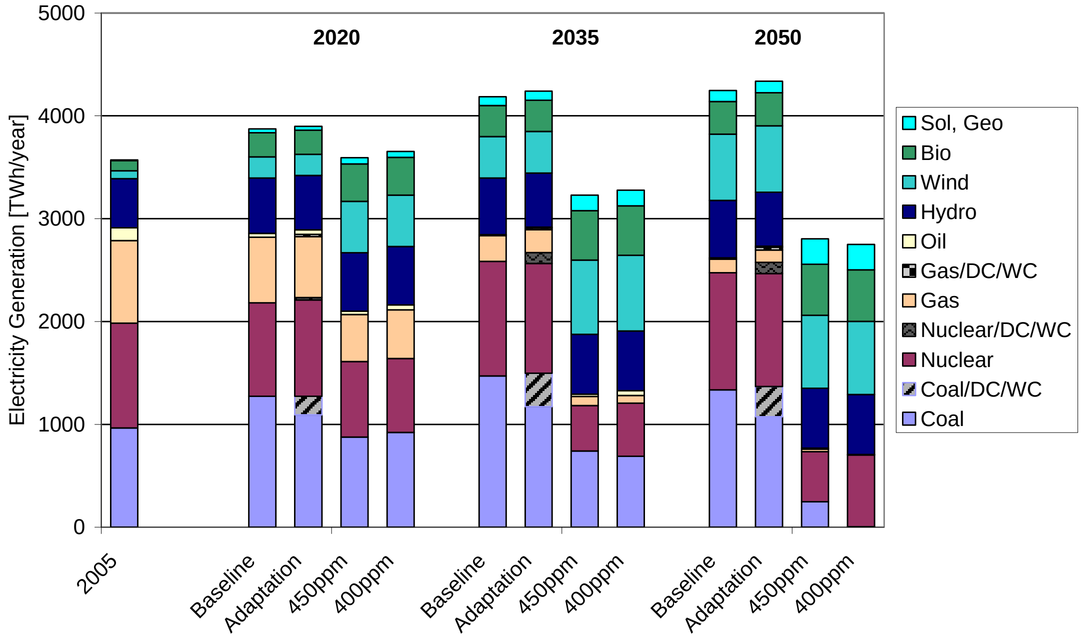
In this section the main results for the European energy conversion sector are presented, focussing on the electricity generation sector.

11.3.1 Electricity generation

Achieving targets of 450ppm or even 400ppm CO_2-eq requires a substantial reduction in CO_2 emissions. In the electricity generation sector in Europe this likely translates to a requirement to decarbonise by 90 to 100% by 2050 for the two scenarios, respectively. To achieve such a reduction, a rapid and large expansion of renewable electricity generation mainly based on new wind, solar and biomass based power generation capacities together with a continued use of nuclear power are mandatory (see Figure 11-1). The use of renewable sources for power generation reaches levels of up to 75% of total generation (including hydro power) in 2050. The remaining share is covered mainly by nuclear power and partly advanced coal powered generation in the 450ppm scenario. Natural gas only plays a minor role for power generation mainly due to the high gas prices in the assumptions. In our analysis the option of carbon capture and storage is too costly compared with other CO_2 free power generation and therefore only plays a marginal role in the energy conversion sector. As described in (Reiter U. and Held A., 2009) and (Jochem et al. 2009) renewable electricity generation in the baseline and adaptation scenario only contributes by approx. 38% whereas coal contributes

[23] In EuroMM 3 seasons (winter, summer and intermediate) and 2 parameters for day and nigth (in each season) are defined.

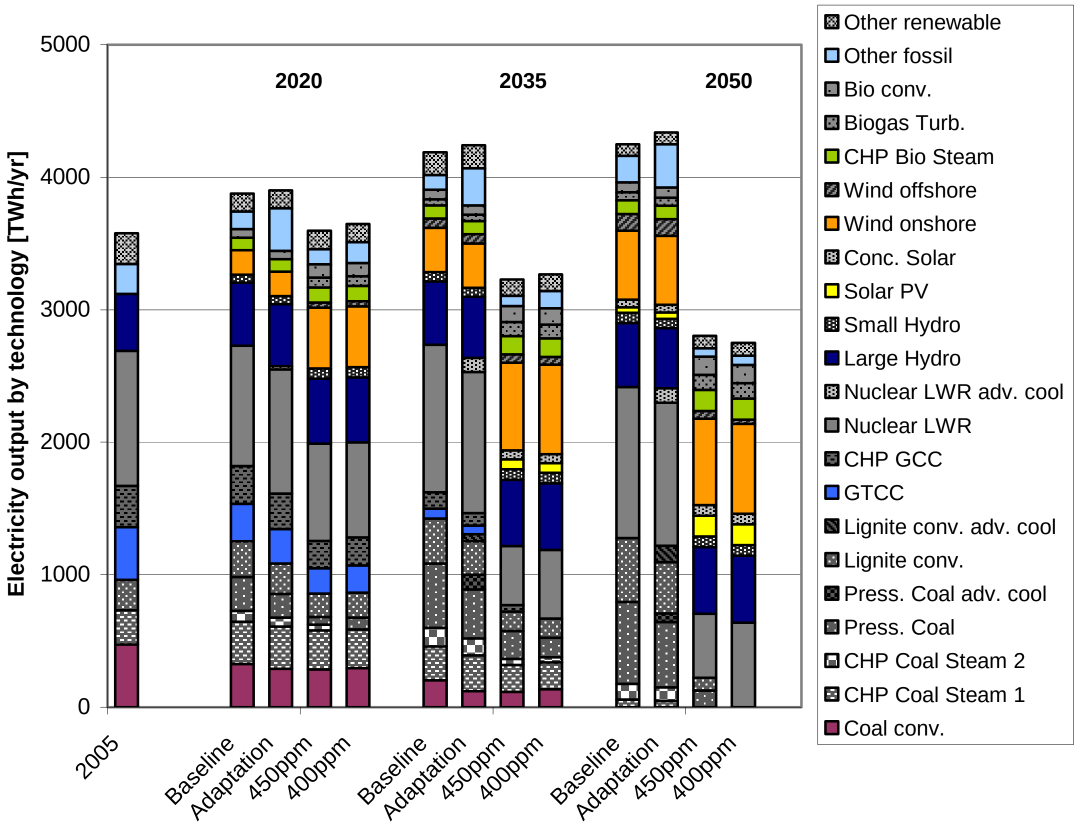
with 31% and nuclear based electricity with 27% to total electricity generation. Further details about the technologies which are used for power generation are shown in Figure 11-2 wheras only technologies are specified which are contributing by more than 2.5 % to total generation.



Source: Euro MM, PSI

Figure 11-1: Electricity generation depending on the fuel type for the 4 ADAM-M1 scenarios. The results are given for the base year and the years 2020, 2035 and 2050. The legend entry DC/WC stands for advanced cooling technologies which are mandatory for the reference scenario which is further described in (Reiter U.,. and Held A., 2009)

As mentioned above and shown in Figure 11-1, by 2050 renewable energy sources account for up to 75% in the two scenarios, with wind and solar generation accounting for 35%. This high share of fluctuating wind and solar pv generation poses some challenges for the electricity system (e.g. baseload generation), but this is managed in this scenario largely through electricity trade between neighbouring countries and extensive grid interconnections. These enable intermittency (particularly of wind) to be managed by integrating regionally diverse generation sites, thus ensuring a higher certainty of dispatch. The high share of renewables is further managed through electricity trade between countries with a high share of non-dispatchable sources and those with more dispatchable sources (nuclear, biomass, hydroelectric and residual fossil capacity). Hydro capacity is also used as a backup for storing excess electricity in times of low demand. In contrast to today's situation where hydro storage is often used for arbitrage, pumped storage only plays the role as backup capacity in our least cost analysis.

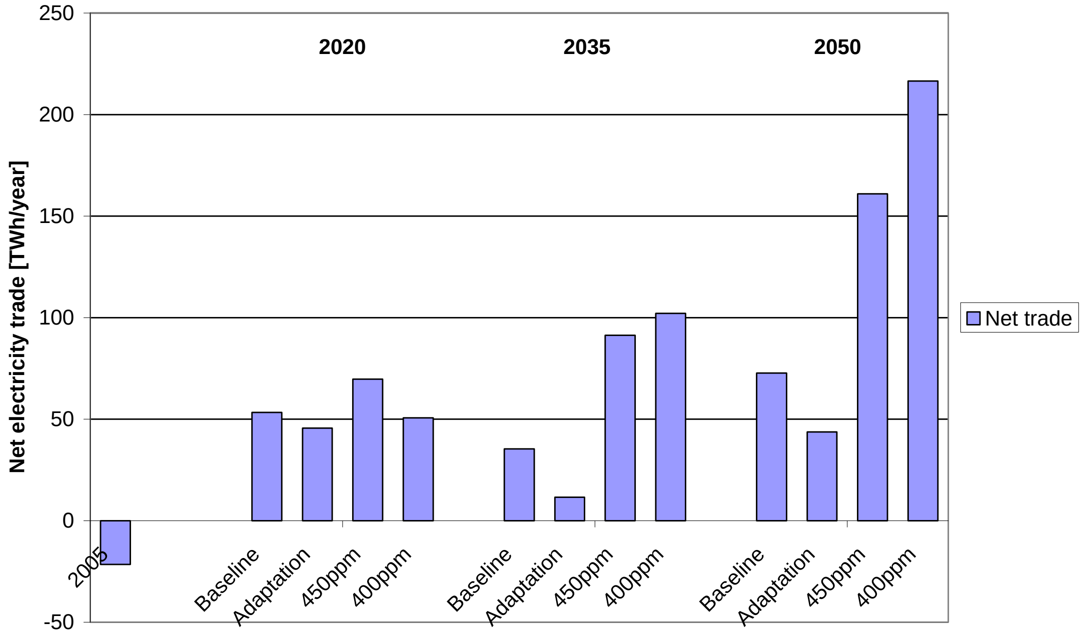


Source: Euro MM, PSI

Figure 11-2: Electricity generation by technology. Only technologies are shown which are contributing by 2.5% in at least one period to total generation in each scenario. Most of the remaining sources of fossil generation (indicated as "Other fossil" in the figure) are combined heat and power technologies (CHP) and other renewable technologies ("Other renewable" in the figure) are mainly based on biomass and geothermal energy

The importance of electricity trade inside the EU, can be best illustrated by looking at results for single regions: for example, without extensive trade links Germany would be unable to achieve stringent mitigation targets, given its policy of phasing out nuclear electricity generation together with limited renewable resources (see Figure 11-3). In the case of Germany we are estimating that approx. 50% of the electricity needs to be imported until 2050 in the 400ppm scenario.[24]

24 One of the important assumptions in our analysis is that we do not consider policies for the security of supply on a country level.



Source: Euro MM, PSI

Figure 11-3: Net electricity trade (i.e., imports) between Germany and its neighbouring countries. In 2005, Germany was a net exporter of electricity

In the different mitigation scenarios the demand for electricity from end-use sectors (residential, services, transport and industry) shows two different trends (see Figure 11-1). The demand for electricity in the residential and service sector decreases further in the 400ppm scenario compared to the 450ppm scenario due to increased energy efficiency, whereas the electricity demand for transport (electric vehicles) increases in the 400ppm scenario due to electrification of the automobile fleet. However, in both scenarios, the total demand for electricity is approx. 35% lower compared to the baseline scenario in 2050.

Details about the results in case of climate change adaptation in the energy conversion sector which are not described in detail in this report can be found in (Reiter U. and Held A., 2009) and the deliverable M1.2 (Jochem et al., 2009)

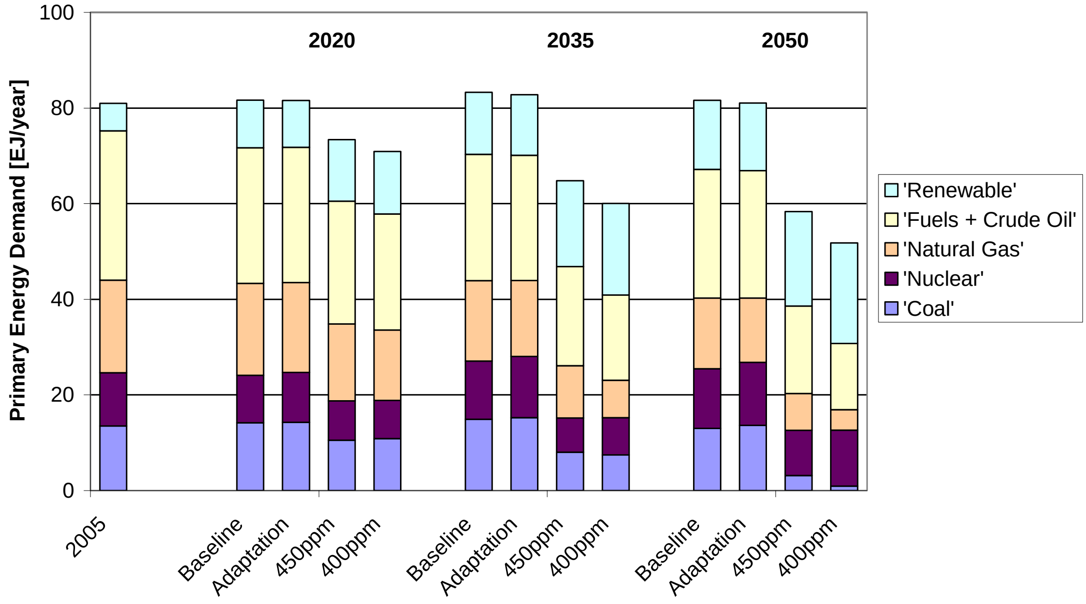
11.3.2 Other energy conversion

In our analysis we also include other forms of energy conversion compared to electricity generation such as coke or briquette production together with refining activities for oil products. However, in all scenarios the activities in these segments are highly depending on the final energy demand for the specific fuels. It is likely that e.g. coke or naphta alternatives in fuel are less available and therefore it is more difficult to fully decarbonise such activities.

11.3.3 Primary energy demand

Similar to the demand reductions for electricity, the demand for other fuels decreases in the climate mitigation scenarios compared to the baseline and adaptation scenarios. Efficiency gains in space heating and appliances along with fuel switching in the residential and services sectors (see section 6 and 7) lead to significant reductions in demand for fossil fuels. A shift to advanced transport technologies allows for further reductions in demand for fossil fuels (see section 9). Fuel savings are also achieved in the electricity generation sector since fossil fuel based technologies are replaced by technologies based on renewable sources (as discussed in section 11.3.1). Additionally, efficiency improvements in generating and distributing electricity are achieved in the scenarios described here. As a result, the overall demand for primary energy is reduced by 28% and 36% in 2050 in the the 450ppm and 400ppm scenario, respectively (see Figure 11-4) compared to the baseline. In the 400 ppm scenario approx. 37% of primary energy is supplied by fossil fuels in 2050, much of which supplies final energy demand directly. For example, 60% of the coal and gas and 50% of the crude oil is used directly in end-use sectors. The remainder is used in the conversion sector, although primarily for production of fuels other than electricity, including heat, coal products and gas. The remainder of primary energy demand is covered by renewable sources[25]—which increase their share from 7% in 2005 to 40% in the 400 ppm scenario as maximum in 2050. Nuclear fuels slightly increase their share from 13% in 2005 to 16% and 22% in the 450ppm and 400ppm scenarios, respectively.

[25] We use the primary energy content principle for all renewable and nuclear sources with a fossil equivalent of 33%.



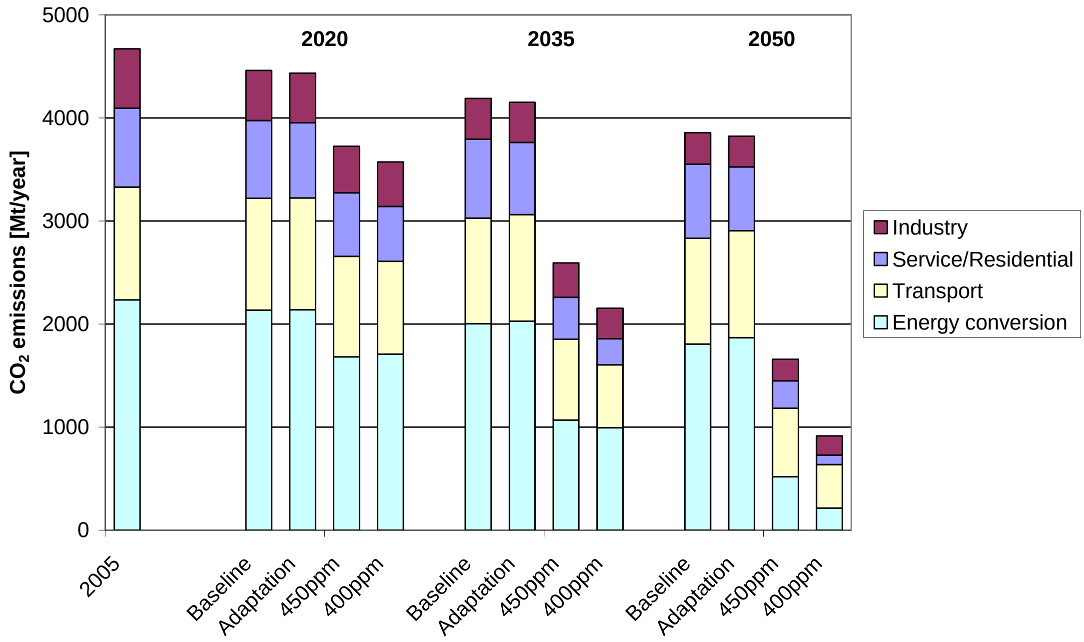
Source: Euro MM, PSI

Figure 11-4: Primary energy demand under the given scenarios. In the mitigation scenarios, fossil fuels reduce their share from 80% to 36% in the 400ppm scenario until 2050

11.3.4 Emissions

Under stringent climate mitigation targets, the annual CO_2 emissions in Europe need to be reduced from 4.7 billion tons (Gt) in 2005 to approx. 1.6 Gt and 1.0 Gt per year in 2050 in the 450ppm and 400ppm scenarios, respectively. Industry contributes with 8% to 12% to the annual emissions in the baseline, adaptation and 450ppm scenarios and the residential and service sectors contribute with 16% to 18% to the annual emissions under the same set of scenarios and across periods. Only in the 400ppm scenario the residential and service sectors can decrease the share in total emissions down to 10% in 2050 whereas the industrial sector increases its share to 20% to the total emissions. However, compared to the baseline and adaptation scenarios, in the 400ppm scenario the specific emissions are reduced by approx. 70% in the industry sector and up to 90% in the residential and service sector until 2050. Looking at the transport sector, achieving these stringent mitigation targets does not necessarily require such large emissions reductions compared to those described for the industry and service and residential sector. The transport sector reduces emissions by approx. 60% in the 400ppm scenario whereas the share in total emissions increases from 23% in 2005 to more than 40% in 2050. In contrast to the transport sector, the energy conversion sector achives very steep emission reductions and reduces its share in total emissions from almost

50% in 2005 down to 23%-30% in the mitigation scenarios. The main contributors to the emissions in the energy conversion sector are the fuel production industries, mainly for transport fuels and coal products.



Source: Euro MM, PSI

Figure 11-5: CO_2 emissions for the given scenarios until 2050. The emission targets for the mitigation scenarios are derived from the global Poles model and adapted to EuroMM (including emissions from transport and coal products)

11.3.5 Investment costs

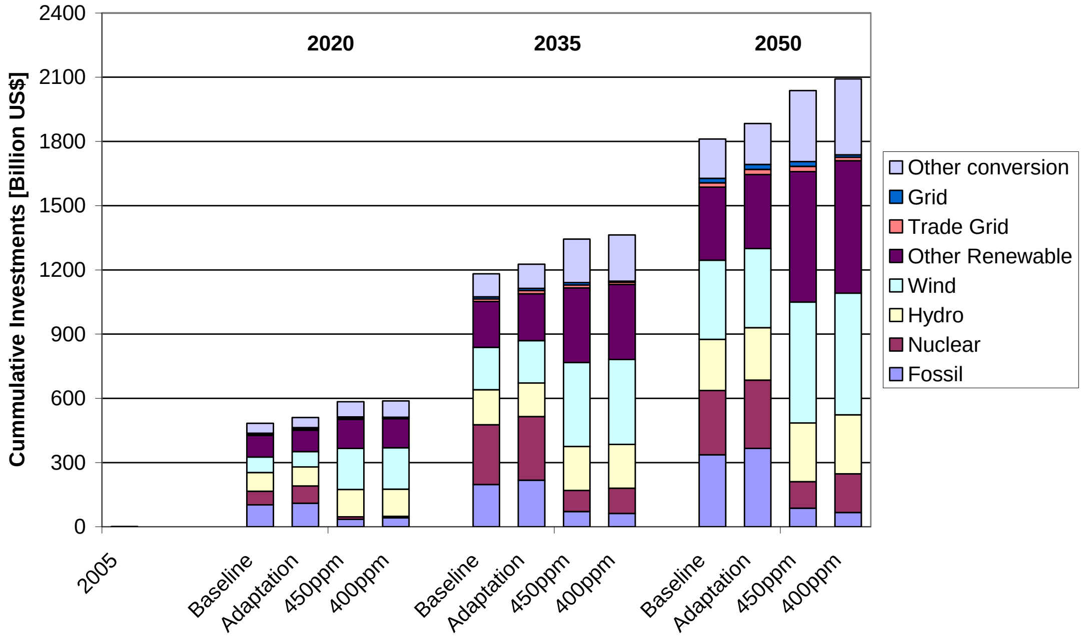
Over the first half of this century substantial new investment will be needed in the energy conversion sector, irrespective of climate change. In fact, the cumulative investment needs in the energy conversion sector out to 2050 are only 12-15% higher in the mitigation scenarios compared to the baseline scenario (see Figure 11-6) and are in the range of $2000 billion to $2100 billion in 2050. The annual investment costs for the energy conversion sector are highest in the years **from** 2020 to 2035 in the range of 1.8% of total GDP and are decreasing thereafter down to 1% of total GDP. The electricity sector, covering up to 91% of total investments shows even smaller differences between the scenarios. This can be explained by a number of factors. In the baseline and adaptation scenarios higher investment is needed to cover growing demands for electricity and carbon based fuels for heating, transportation, industry and others (see Jochem et al, 2009). In the mitigation scenarios, the demand for energy is reduced significantly, so less conversion capacity is needed. However, this is offset by the need for more costly conversion technologies with a lower CO_2-intensity.[26] In the 450ppm and 400ppm scenario, the majority of investments are needed in renewable energy technologies, with an equal distribution between wind- and solar-based electricity generation which need investments in the range of $560 billion and $600 billion, respectively (compare also with section 10).[27] However, the need for investments in renewable generation may be slightly overestimated since our analysis in EuroMM uses conservative estimates for capacity factors, particularly in those regions with high renewable potentials (e.g. UK for wind and IBE for solar).

The additional investment in the grid infrastructure only takes up a small share in total investment. This is mainly due to low investment cost for new transmission lines (assumed to vary between $230,000 and $650,000 per km of high voltage transmission line) compared to investments in generation capacity.

Further investments are needed for producing low temperature heat and alternative fuels such as biofuels and hydrogen for transport. The needed investments in the sectors others then electricity are in the range of $180 - $190 billion in the baseline and adaptation scenario. In the 450ppm and 400ppm scenario the needed investments are in the range of $330 to $350 billion, respectively. Additional investments needed to achieve efficiency improvements in the final energy sectors are described in the sections 6 to 9 of this report.

[26] In addition, more investment is needed in the end-use sectors on efficient technologies, as discussed in chapters 6 and 9.

[27] It should be noted that the cost per kW is higher for solar capacity, hence there is much larger installation of wind capacity.



Source: Euro MM, PSI

Figure 11-6: Cummulative investment costs in the energy conversion sector for the 4 scenarios. Results are given in US$ (2001). The needed investment for the electricity grid infrastructure is given for transmission lines whithin regions (Grid) and cross boarder trade (Trade Grid)

11.4 Conclusion on policies to achieve sectoral changes

A number of important changes are required in the conversion sector to achieve the stringent mitigation targets explored in this analysis. These include phase-out of CO_2 emitting fossil generation, large-scale deployment of renewables, and a continued deployment of nuclear energy. As discussed in section 10, realising the high level of renewable power generation is likely to necessitate substantial government support over a long period (achievable through a range of measures such as feed in tarifs or cap and trade systems). Maintaining and expanding deployment of nuclear energy will likely require a different type of policy support to address concerns regarding waste disposal, risk of accidents and nuclear proliferation, thus ensuring sufficient public support. The phase-out of CO_2 emitting fossil generation will be brought forward by high and stable CO_2 prices which are likely to be achieved by CO_2 taxes or cap and trade systems. In addition to these measures, one of the most important areas for policy intervention to achieve cost-effective mitigation targets may be in supporting open and efficient markets for electricity trade. This was illustrated by the importance of trade for managing the large-scale deployment of renewables and providing additional flexibility where countries have lower access to hydroelectric, nuclear or other generators that can be operated more or less on demand. Exploiting the renewable potentials in those regions where they are highest, together with the unconstrained option for trading electricity to centres with high demand is therefore essential. It is in the interest of the European member states to secure the electricity exchange across boarders and among reliable partners. However, national concerns about security of supply are not included in this results.

In our analysis of the adaptation scenario (see Reiter U. and Held A., 2009) we show the relevance of looking into the needs of adapting the energy conversion sector to climate change. Also in the case of mitigation, climate change impacts are expected to influence the energy conversion sector. However, the impacts of mitigated climate change on efficiency losses and the availability of cooling water are negligibale for the time horizon we are looking at.

12 Synthesis of sectoral analysis in Europe

Authors: Wolfgang Schade, Giacomo Catenazzi, Tobias Fleiter, Anne Held, Nicki Helfrich, Martin Jakob, Eberhard Jochem, Silvana Mima, Ulrich Reiter, Hal Turton.

This section compares the results of the ADAM hybrid model system (HMS) with those of the POLES model. In particular, the bottom-up results of the different sectors can be compared. Differences between the two approaches exist concerning four issues:

(1) POLES directly includes the global level in its considerations, while the ADAM-HMS considers the global level only indirectly via the climate policy framework in the form of a GHG emissions path provided by POLES, but then focuses on the EU-27 countries plus Norway and Switzerland, only.

(2) The ADAM-HMS allows for a flexible response of the economy to climate policy, i.e. it considers changes of GDP as well as structural economic changes, while POLES runs the same economic development path in all scenarios.

(3) The POLES model estimates specific fossil fuel prices for each scenario, i.e. fuel prices before taxes and CO_2 prices. In the ADAM-HMS, only the electricity price changes depending on the power plant mix, while the net fossil fuel prices remain the same, besides in EuroMM.

(4) In parts, the level of technological detail or details of demand structures in the ADAM-HMS will be higher than in POLES, as the single ADAM-HMS models are specialised sectoral models, while POLES is an integrated world energy system model.

The comparison starts with a presentation of the framework variables used in the two approaches which provide the baseline for the comparison and an overview of the results of both approaches on energy demand and GHG emissions in the 400 ppm scenario. This is followed by the five sectoral comparisons of residential/services, industry, transport, renewables and the conversion sector. The final section presents conclusions on the policy implications that can be drawn from the bottom-up analysis.

12.1 Comparison of common framework variables

The major framework variables that have to be considered when comparing the results are: population, GDP and the price of carbon or CO_2, which can be represented by comparable indicators like a CO_2 certificate price or a carbon tax level.

Table 12-1 shows the population development in the ADAM-HMS and the POLES models. The two approaches show a comparable level and trend. Both start in 2010 with 492 million persons for the EU27 and reach 472 and 471 million persons in 2050, respectively. Thus the EU27 growth rate is also comparable with an average annual loss of -0.10 % and -0.11 % in the ADAM-HMS and in POLES. On a regional level there is a slightly stronger population decline for southern and eastern countries in POLES than in the ADAM-HMS.

Table 12-1: Population in the ADAM-HMS and POLES simulations

ADAM-HMS										
	Reference Scenario [million persons]					Changes [%] (average annual population change)				
Country group	2010	2020	2030	2040	2050	'20 to '10	'30 to '20	'40 to '30	'50 to '40	'50 to '10
North	25	25	26	26	26	0.27%	0.20%	0.10%	-0.05%	0.13%
South	155	155	152	147	140	0.00%	-0.21%	-0.34%	-0.47%	-0.25%
East	72	71	69	67	64	-0.19%	-0.25%	-0.36%	-0.40%	-0.30%
West	253	258	260	259	254	0.19%	0.09%	-0.04%	-0.19%	0.01%
EU27	**492**	**496**	**494**	**486**	**472**	**0.08%**	**-0.04%**	**-0.17%**	**-0.29%**	**-0.10%**
POLES model										
	Reference Scenario [million persons]					Changes [%] (average annual population change)				
Country group	2010	2020	2030	2040	2050	'20 to '10	'30 to '20	'40 to '30	'50 to '40	'50 to '10
North	25.6	26.3	26.9	27.1	27.2	0.27%	0.22%	0.07%	0.04%	0.15%
South	152.9	151.0	147.1	142.7	136.9	-0.12%	-0.26%	-0.30%	-0.42%	-0.28%
East	74.0	72.6	69.7	65.9	61.8	-0.20%	-0.39%	-0.56%	-0.64%	-0.45%
West	252.1	256.3	259.4	259.8	258.5	0.17%	0.12%	0.01%	-0.05%	0.06%
EU27	**492**	**494**	**490**	**482**	**471**	**0.03%**	**-0.07%**	**-0.16%**	**-0.23%**	**-0.11%**

Source: ASTRA and POLES

Table 12-2 presents the comparison for GDP between the ADAM-HMS and POLES, which has to take into account that the two approaches use different GDP concepts (e.g. GDP based on PPPs in POLES) and price bases, which had to be converted into the same base. For the EU27 as a whole, the GDP numbers are comparable in 2010. However, the distribution of GDP over the regions differs: POLES has lower GDP in the western European countries and a higher one in the southern and eastern European countries. This results from the PPP point of view.

In terms of growth rates, the basic observation for the EU27 is that in the first decade the POLES model expects higher growth, but overall between 2010 and 2050, both approaches predict the same average annual growth of GDP of 1.6 % and in both cases the growth rates decline decade by decade. There are differences in the growth rates for eastern European countries, which in general are higher in the ADAM-HMS and the growth rates for southern European countries, which are higher in POLES.

Overall, the framework of population and GDP development of POLES and the ADAM-HMS seems to be comparable.

Table 12-2: GDP in the ADAM-HMS and POLES simulations

ADAM-HMS										
	Reference Scenario [billion €$_{2005}$]					Changes [%] (average annual GDP growth)				
Country group	**2010**	**2020**	**2030**	**2040**	**2050**	**'20 to '10**	**'30 to '20**	**'40 to '30**	**'50 to '40**	**'50 to '10**
North	972	1,186	1,414	1,639	1,885	2.0%	1.8%	1.5%	1.4%	1.7%
South	2,499	2,873	3,258	3,600	3,971	1.4%	1.3%	1.0%	1.0%	1.2%
East	462	640	838	1,061	1,240	3.3%	2.7%	2.4%	1.6%	2.5%
West	8,157	9,804	11,551	13,418	15,318	1.9%	1.7%	1.5%	1.3%	1.6%
EU27	**11,483**	**13,750**	**16,174**	**18,704**	**21,260**	**1.8%**	**1.6%**	**1.5%**	**1.3%**	**1.6%**
POLES model										
	Reference Scenario [billion €$_{2005}$]					Changes [%] (average annual GDP growth)				
Country group	**2010**	**2020**	**2030**	**2040**	**2050**	**'20 to '10**	**'30 to '20**	**'40 to '30**	**'50 to '40**	**'50 to '10**
North	650	799	946	1,078	1,206	2.1%	1.7%	1.3%	1.1%	1.6%
South	3,113	3,859	4,492	5,046	5,535	2.2%	1.5%	1.2%	0.9%	1.4%
East	1,064	1,392	1,755	2,153	2,587	2.7%	2.3%	2.1%	1.9%	2.2%
West	6,788	8,375	9,884	11,299	12,689	2.1%	1.7%	1.3%	1.2%	1.6%
EU27	**11,443**	**14,209**	**16,818**	**19,282**	**21,690**	**2.2%**	**1.7%**	**1.4%**	**1.2%**	**1.6%**

Source: ASTRA and POLES model converted to the same price base

There is a larger difference for the prices of CO_2 and the carbon value, respectively. The ADAM-HMS applies a certificate system for CO_2 (emissions trading system) for which either the bottom-up models endogenously calculate the certificate price, or they receive an exogenous certificate price from one of the other bottom-up models. POLES calculates a carbon value that should be added on as a tax to carbon emitting processes. For comparison reasons, this carbon value is converted into a CO_2 price.[28]

Two issues have to be discussed here: First, in its final simulations, the ADAM-HMS did not yield a common, unified CO_2 certificate price. This is due to the iterative process of running the bottom-up models and the sensitivity of the CO_2 price estimation. There is one bottom-up model that contains the GHG emission information from all the bottom-up models, which is

[28] The conversion from carbon to CO_2 uses the factor 3.67 that is recommended by the UK Defra http://www.defra.gov.uk/environment/climatechange/research/carboncost/step1.htm.

then able to determine the CO_2 price. This is the EuroMM model, which models the energy conversion sector. In the simulation process, the bottom-up models besides EuroMM start with an initial CO_2 price from the very first POLES simulation and obtain a sectoral energy demand result (e.g. in the residential or transport sector), which is delivered to EuroMM. EuroMM then aggregates all the energy demand and CO_2 emissions results and estimates a new CO_2 price. This CO_2 price is fed back into the other bottom-up models, which obtain new results for energy demand with the new CO_2 price. The simulation process runs iteratively and ideally converges to a CO_2 price which does not change anymore or only marginally between two iterations. Unfortunately, the number of iterations which could be feasibly managed in the project was limited and the sensitivity of the CO_2 price optimisation was high, so that simulation stopped before full convergence could be achieved. This results in CO_2 prices that are not completely congruent in the ADAM-HMS. The left-hand side of Figure 12-1 presents the CO_2 prices of EuroMM and ASTRA calculated or used in their last iteration. It is obvious that, in EuroMM, the cap on CO_2 emissions only becomes effective after 2040 when the CO_2 price rockets, in particular in the 400 ppm scenario, which also means that it is difficult or simply impossible for large-scale systems (e.g. energy, housing) to react to mitigate this price increase because of the inertia and time lags in the systems. ASTRA used a smoothly increasing price from earlier iterations, which ended at a higher level in the 450 ppm scenario and a lower one in the 400 ppm scenario than in the final EuroMM iteration.

The second issue to be mentioned is the difference in price levels between POLES and the ADAM-HMS. As can be observed from Figure 12-1, in the 450 ppm scenario, POLES reached a price of about 250 €/tCO_2, while in the ADAM-HMS this remained between 20 and 80 €/tCO_2. There seem to be a number of possible reasons for this: (1) The ADAM-HMS applies immediate actions such that the price path of CO_2 remains low in the first decades as no scarcity emerges due to the early reduction actions. (2) In the ADAM-HMS, besides carbon pricing, sectoral policies are also applied so the pressure for GHG emission reductions does not have to come from the CO_2 pricing system alone. (3) The possibility of barrier removal when implementing measures and new technologies seems to be treated more optimistically in the ADAM-HMS than in POLES.

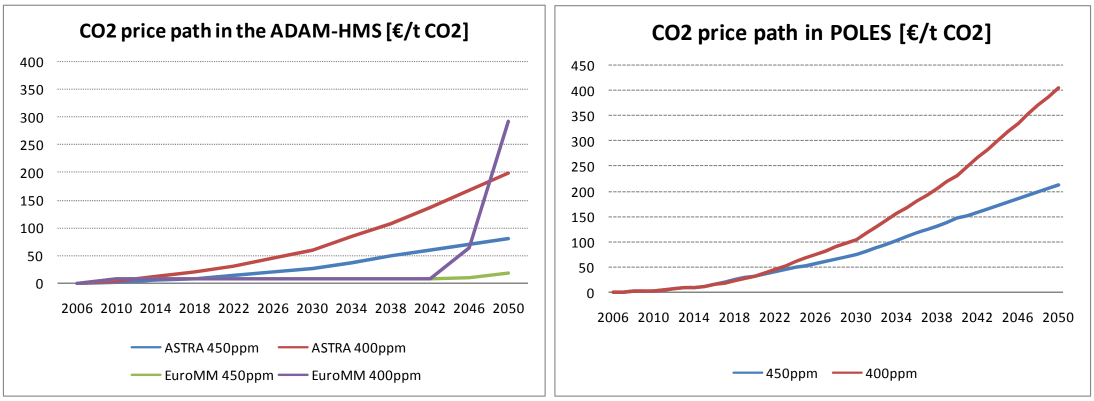


Figure 12-1: CO_2 certificate price in ADAM-HMS and in POLES

12.2 Overview comparing the energy and emission trends of ADAM-HMS and POLES

The European Commission has defined the target that temperature increases due to global climate change should not exceed 2 degrees Celsius in 2100 relative to preindustrial levels. To achieve this climate change mitigation target, stringent GHG emission reductions need to be made in the coming decades. However, it is still unclear which levels of CO_2 concentration are acceptable to achieve this target. Climate scientists agree that limiting the CO_2 concentration to 400 ppm gives an 80 % chance of meeting the proposed 2°C target [Meinshausen et al. 2009]. If CO_2 concentrations can only be stabilized at 450 ppm, the probability of meeting the target decreases to 50 %. For both scenarios, the impacts on the European energy sector were analysed using the POLES model and the ADAM hybrid model system, respectively.

Given that the emission profile for Europe is defined by the global POLES model for the 450 ppm and the 400 ppm scenarios (see section 4), our analysis shows that at least two different pathways are feasible to achieve stringent climate mitigation targets under the given set of assumptions. According to the results of both bottom-up approaches defining the European energy conversion sector, the European climate target of 2°C can be achieved by a rapid and large deployment of renewable energies together with effective efficiency improvements, mainly in the final energy demand sectors.

An alternative pathway is shown by the POLES model, which assumes lower efficiency improvements, a later point in time at which technological change and behavioural change start to occur and a higher deployment of fossil technologies equipped with carbon capture and sequestration (CCS). In this sense, the ADAM-HMS suggests an immediate action path, while the POLES model describes a development which is close to business-as-usual until 2020 followed by a trend break leading to a moderate decline of energy demand.

The pathways of final energy demand in ADAM-HMS (left-hand side) and POLES (right-hand side) for the 400 ppm scenario are shown in Figure 12-2. Both pathways shown in this analysis require stringent policies and support to be able to meet the targets set by the European Commission. In the ADAM-HMS, the support would have to start earlier and concentrate on fostering renewable energies and efficiency technologies (e.g. fuel efficiency standards of cars, insulation of buildings, top runner approach to electric appliances), while, in POLES, efficiency policies play a much smaller role and priority is given to the use of biomass and to carbon removal technologies, i.e. foster R&D and the introduction of CCS.

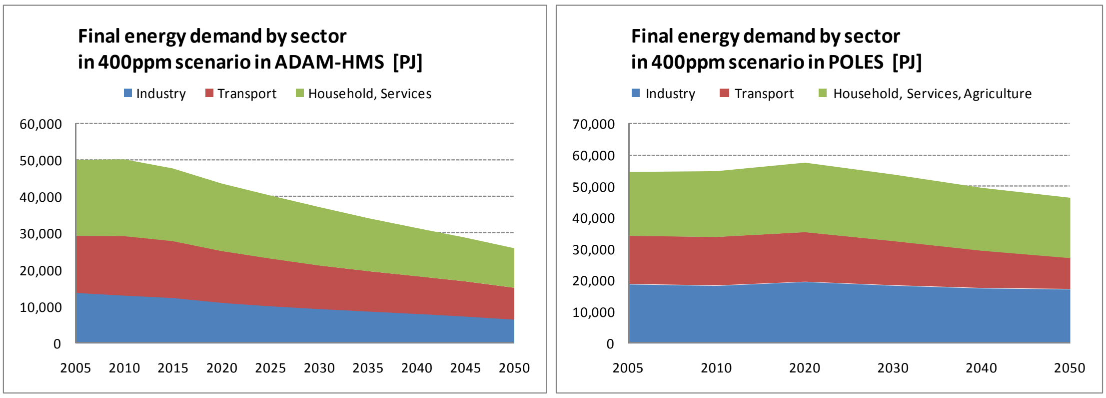


Figure 12-2: Energy demand by sector of EU27 in ADAM-HMS and POLES (400 ppm scenario)

Looking at the more detailed developments of energy demand in Table 12-3, it can be observed that, in the ADAM-HMS, the sectoral energy demand is reduced by -48 % until 2050 compared with 2010, while in POLES, the reduction amounts to -15 %, only. The sectoral structure of reductions differs significantly. The total reductions are closest for the transport sector (-47 % and -36 %), while they differ significantly for industry and household/services, which cut demand by about half until 2050 in the ADAM-HMS, but by less than -10 % in POLES.

Table 12-3: Development of final energy demand in ADAM-HMS and POLES (400 ppm scenario)

	ADAM-HMS					POLES				
	Average annual change				Total change	Average annual change				Total change
	20 to 05	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**	**20 to 05**	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**
Industry	-1.4%	-1.6%	-1.8%	-1.7%	-50%	0.3%	-0.6%	-0.3%	-0.2%	-6%
Transport	-0.7%	-1.8%	-1.6%	-1.6%	-47%	0.2%	-1.1%	-1.8%	-1.1%	-36%
Household, services, agriculture	-0.8%	-1.4%	-1.9%	-1.6%	-49%	0.6%	-0.4%	-0.5%	-0.2%	-8%
Total	-0.9%	-1.6%	-1.8%	-1.6%	-48%	0.4%	-0.7%	-0.7%	-0.4%	-15%

Source: ADAM-HMS and POLES

Figure 12-3 presents the path for the CO_2 emissions in EU27 by sector for the ADAM-HMS and the POLES model. Reductions start around 2010 in both ADAM-HMS and POLES, although the reductions in POLES until 2020 are moderate compared with the ADAM-HMS efforts that reflect the immediate actions to reduce energy demand described above. A difference exists concerning energy conversion, for which negative CO_2 emissions occur in POLES in 2050 due to CCS, while in the ADAM-HMS CCS is not applied to energy conversion at all.

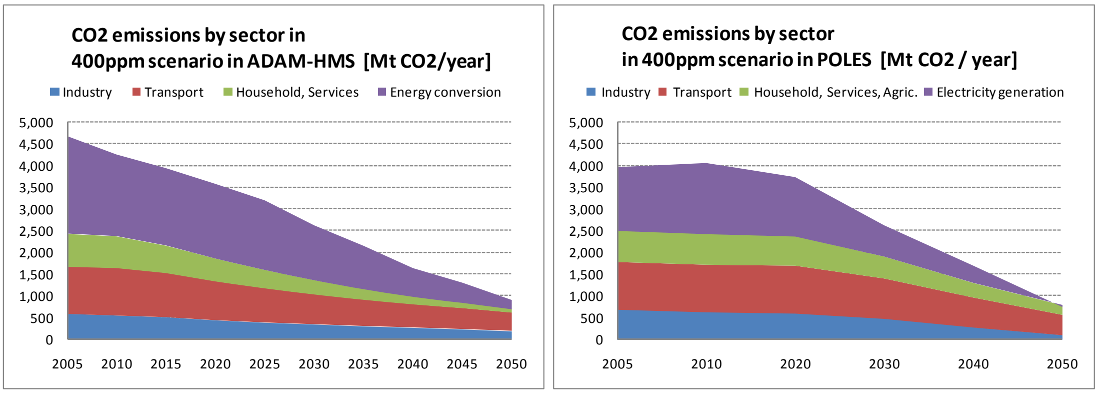


Figure 12-3: CO_2 emissions by sector of EU27 in ADAM-HMS and POLES (400 ppm scenario)

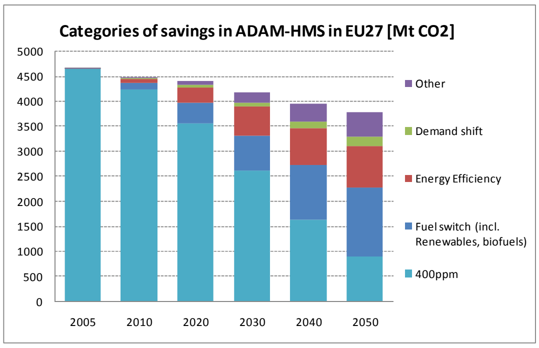
Looking at the sectoral details of CO_2reductions in Table 12-4, it is once again clear that the results are closest for the transport sector, with a CO_2 reduction of -62 % until 2050 compared with 2010 in the ADAM-HMS and -58 % in the POLES model. For the industry sector, the POLES model expects a more ambitious reduction path, while for household/services, the ADAM-HMS expects the largest reduction of all final energy sectors with -88 % CO_2. For energy conversion/electricity generation, the diffusion of CCS technologies results in a stronger reduction in the POLES model amounting to -103 %, which means that CO_2 is removed from the atmospheric CO_2 cycle and stored underground due to the use of CCS and biomass in electricity generation.

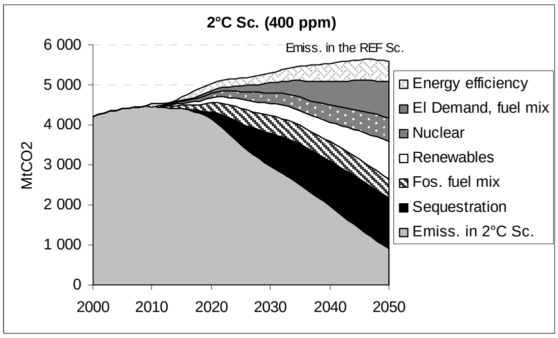
Table 12-4: Development of CO_2 emissions in ADAM-HMS and POLES (400 ppm scenario)

	ADAM-HMS					POLES				
	Average annual change				Total change	Average annual change				Total change
	20 to 05	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**	**20 to 05**	**30 to 20**	**50 to 30**	**50 to 10**	**50 to 10**
Industry	-1.9%	-2.4%	-2.9%	-2.6%	-65%	-0.9%	-2.2%	-7.4%	-4.4%	-84%
Transport	-1.3%	-2.6%	-2.4%	-2.4%	-62%	0.0%	-1.7%	-3.4%	-2.1%	-58%
Household, services, agriculture	-2.4%	-4.5%	-6.3%	-5.1%	-88%	-0.4%	-2.9%	-4.0%	-2.8%	-69%
Energy conversion / elec. generation	-1.8%	-3.0%	-8.5%	-5.3%	-89%	-0.5%	-4.9%	~ -28%	~ -16%	-103%
Total	-1.8%	-3.0%	-5.1%	-3.8%	-78%	-0.4%	-3.1%	-6.0%	-4.0%	-81%

Source: ADAM-HMS and POLES

Figure 12-4 presents the categorisation of sources of CO_2 savings for the ADAM-HMS (left hand side) and POLES (right hand side). In both figures the top line of the curve represents the CO_2 emissions in their reference scenario and the bottom area the CO_2 emissions in the 400 ppm scenario. Inbetween the top line and the bottom area are the wedges of the different categories of CO_2 emission reductions. Accounting in POLES four categories into the fuel switch to make it roughly comparable with the ADAM-HMS (change of fuel mix of electricity and at the demand level, nuclear and renewable energies) it shows that this category reveals the highest contribution with about 50 % share in ADAM-HMS and 60 % in POLES. However, nuclear plays a very limited role in the ADAM-HMS, while the relative weight of renewable energies is significantly higher than in POLES. The largest differences exist concerning energy efficiency, which in the ADAM-HMS accounts for about one third of CO_2 savings, and in POLES for about one tenth, only. CCS contributes roughly one third in POLES, while it is only a small part of the other category in the ADAM-HMS with about 3 % of total CO_2 savings.

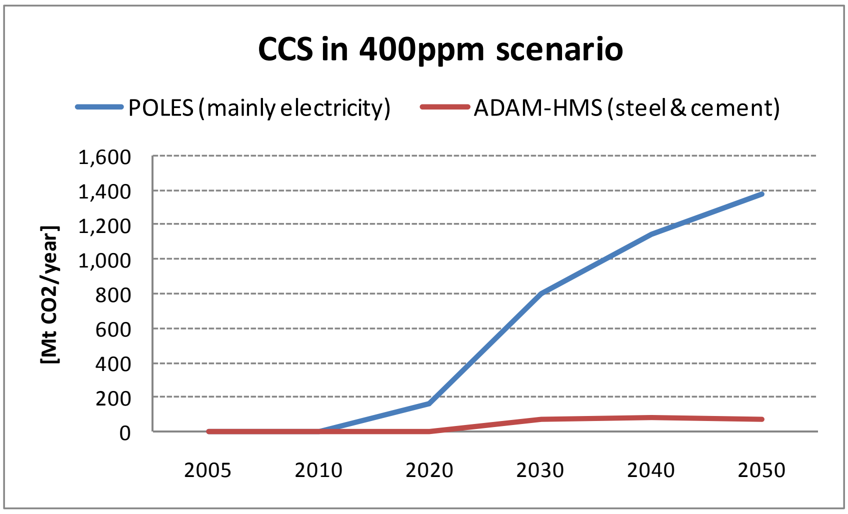




Source: ADAM-HMS and POLES

Figure 12-4: Comparison of categories of CO_2 savings in EU27 in ADAM-HMS and POLES (400 ppm scenario)

Figure 12-5 presents the diffusion of CCS as estimated in ADAM-HMS and POLES. The POLES model estimates that about 65 % of the 2050 emissions of CO_2 will be reduced by CCS, of which the largest part comes from electricity generation. In the ADAM-HMS, CCS is only applied in industrial processes, e.g. for the production of steel and cement. Thus the quantity of CO_2 that needs to be stored is much lower.



Source: DAM-HMS (ISIndustry) and POLES model

Figure 12-5: CCS in EU27 in ADAM-HMS and POLES model (400 ppm scenario)

12.3 Comparison of residential and service sectors: POLES and three bottom-up models of the ADAM-HMS

The results of the residential and the service sector are compared jointly. The comparison discusses the results between the POLES model on the one hand and CEPE's bottom-up models RESIDENT, RESAPPLIANCES and SERVE on the other. The models use different assumptions about drivers and technology. To a certain extent, the two model systems also have a differently detailed structure which hampers a comprehensive comparison and which does not allow the assumptions about structural changes to be compared. In this section, we limit the comparison to the most important drivers, the main technical assumptions and the results of EU27+2 countries.

In the residential sector, both POLES and CEPE's models use basically the same drivers. Heating energy and other substitutable energies are based on floor area. Electricity for appliances is modelled based on the number of households. The floor area in the residential sector evolves in more or less the same way: It increases by +26 % in the POLES model and by +40 % in RESIDENT (Table 12-5). In POLES, the number of households increases by +7 %, and by +22 % in RESAPPLIANCE.

In the service sector there are different quantitative drivers in POLES and SERVE: whereas energy demand is linked to economic indicators (value added of different sub-sectors) in the POLES model, it is based on physical drivers in SERVE (floor area). These two sets of drivers differ significantly in their development: whereas the value added in POLES increases by +100 % (i.e. it more or less doubles), the floor area in SERVE increases only by about +40 % (Table 12-5) taking into account higher labour productivity and automation in the various service sectors. Hence, POLES is based on quantitative drivers that increase to a much greater extent than those in SERVE. In addition, the development of the value added of the service sector until 2050 does not change in the two scenarios in the POLES model, while value added and floor area of the service sector are slightly reduced in the 2°C Scenario.

Table 12-5: Most important drivers in the models POLES, RESIDENT, RESAPPLIANCE and SERVE for the EU27+2 countries, Reference and 2°C Scenario. 2005 to 2050

	POLES					RESIDENT, RESAPPL., SERVE				
	2005	2050		2005 / 2050		2005	2050		2005 / 2050	
		Ref.-Scen.	2°C-Scen.	Ref.-Scen.	2°C-Scen.		Ref.-Scen.	2°C-Scen.	Ref.-Scen.	2°C-Scen.
Population (million)	514	498	498	-4%	-4%	503	487	487	-3%	-3%
No. of dwellings (million)	238	249	249	+7%	+7%	199	243	243	22%	22%
Floor area residential	19.6	24.7	24.7	26%	26%	17.6	24.6	24.6	40%	40%
Value added services (billion €)	5,793	11,65	11,65	100%	100%	6,430	15,76	15,24	145%	137%
Floor area services	n.a.	n.a.	n.a.	-	-	7.2	11.4	11.3	58%	57%

Source: POLES' and CEPE assumptions

Next to quantitative drivers, the future energy demand of the residential and service sectors is strongly dependent on assumptions regarding energy-efficiency developments in buildings, appliances, lighting and other processes. Due to the different underlying model structure, there are only a few directly comparable energy-efficiency indicators.

One such indicator is the diffusion of the share of energy-efficient buildings. The fact that the CEPE models show greater progress is due in part to the assumed wider diffusion of low-energy buildings (see Table 12-6). In the POLES model, about one third of buildings is assumed to comply with a strict energy standard in the year 2050, whereas in RESIDENT about 80 % of buildings are assumed to meet this standard in the 450 ppm variant of the 2°C Scenario. In POLES, about 40 % of buildings are still of standard efficiency, even in the 400 ppm scenario variant. Hence the assumptions in the model RESIDENT are much more ambitious in terms of the diffusion of energy-efficient buildings, i.e. they project a more ambitious and successful energy policy in buildings and related building management systems.

Moreover, RESIDENT has a more detailed model structure, which differentiates explicitly between existing buildings and new buildings, whereas POLES models the structural change due to more new buildings only implicitly through the reduced specific heat demand of the building stock. Differentiating between new and existing buildings allows building codes and technical standards to be explicitly modelled that usually only apply to new buildings, but can also be applied to buildings to be retrofitted under new legislation in European countries. The explicit simulation of those policies results in more transparency regarding these assumptions.

Table 12-6: Share of buildings in line with low-energy standards in POLES and in RESIDENT for the residential sector, Europe, Reference Scenario and the two variants of the 2°C Scenario, 2050

type of building code	POLES			RESIDENT and SERVE		
	Reference	**450 ppm**	**400 ppm**	**Reference**	**450 ppm**	**400 ppm**
Standard	97%	54%	39%	70%	20%	0%
Low energy	3%	36%	45%	30%	80%	20%
Very low energy	0%	9%	16%	0%	0%	80%

Source: POLES' and CEPE assumptions

Against the above described background regarding the different developments of the drivers and efficiency indicators, it is no surprise that the final energy demand differs between the two model systems already in the Reference Scenario: It increases by +33 % in POLES and only by +5 % in the CEPE models (see Table 12-8 and Figure 12-6). Regarding final energy demand in the 2°C Scenario, both models show significant improvements in the two variants compared to the Reference Scenario: In POLES, the resulting final energy demand of the two sectors is reduced by -21 % in the 450 ppm variant and in the CEPE models by -48 % in 2050; for the 400 ppm variant, the reduction is -29 % (POLES) and -64 % (CEPE).

Hence, there are two major differences in the resulting final energy demand between the two modelling systems:

- In the Reference Scenario, final energy demand increases considerably in POLES, whereas it is more or less stable in CEPE’s bottom-up models.
- The relative difference between the Reference Scenario and the two mitigation scenarios is distinctly larger in the CEPE models.

These two differences explain the considerable difference in the final energy demand of the two variants of the 2°C Scenario between POLES and the other models. Compared to 2005, mitigation measures are able to more or less stabilize total final energy demand in the case of the POLES model and significantly reduce it in the CEPE models: by about 50 % in the 450 ppm scenario variant and by about two thirds in the more ambitious 400 scenario variant (see Table 12-8). Obviously, such a large difference has implications with regard to direct CO_2 emissions, but also with regard to indirect ones such as those related to electricity demand.

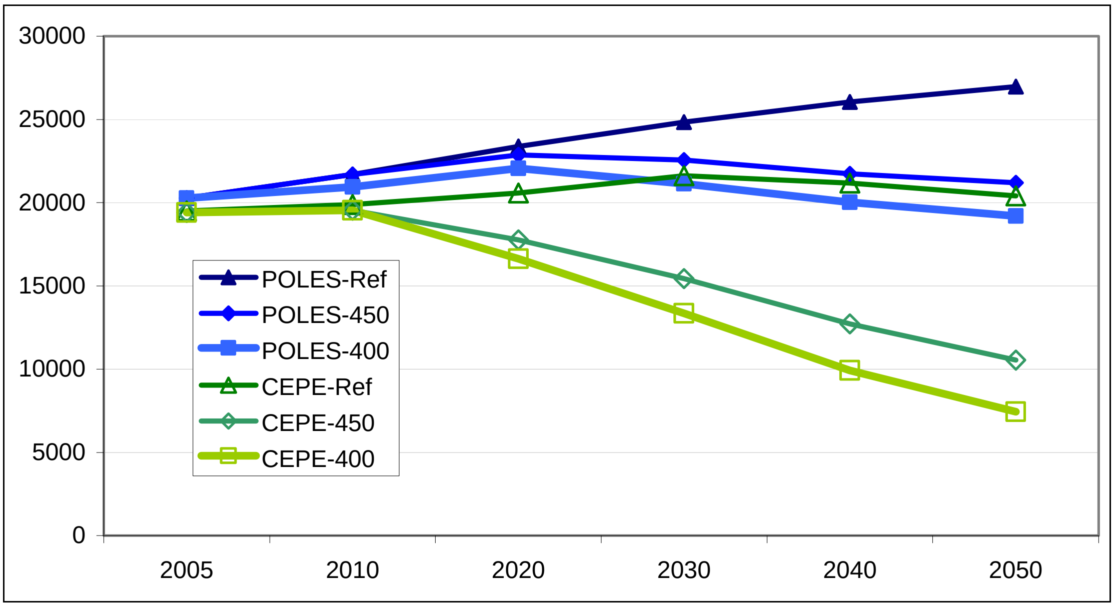


Figure 12-6: **Comparison of final energy demand (in PJ) for the residential, service and agricultural sectors in POLES and the three CEPE models for the Reference Scenario and the two variants of the 2°C Scenario, 2005 to 2050**

Also, the results of the two model systems differ to a certain extent regarding the development of the individual final energy shares (Table 12-7).

Table 12-7: **Relative break down of the final energy demand of the residential, service and agriculture sectors, 2005 and 2050, Reference and 2°C Scenario, EU27+2**

	POLES	Ref.-Scen.	2°C Scenario		CEPE	Ref.-Scen.	2°C Scenario	
			450 ppm	400 ppm			450 ppm	400 ppm
	2005	2050	2050	2050	2005	2050	2050	2050
Heating oil	20%	16%	8%	7%	18%	10%	5%	4%
Nat. gas	36%	28%	14%	12%	37%	37%	34%	12%
Coal	2%	0%	0%	0%	2%	1%	0%	0%
Electricity	27%	37%	46%	47%	30%	41%	46%	64%
Biomass	7%	9%	17%	21%	5%	6%	11%	16%
District heat	8%	10%	15%	13%	7%	5%	4%	3%

Source: POLES' and CEPE assumptions

However, the differences become more apparent when analysing the breakdown of the final energy demand in absolute terms: In POLES, the demand for both electricity and other fuels increases considerably between 2005 and 2050 in the Reference Scenario (see Table 12-8). Even the demand for fossil fuels grows by some 25 %. Conversely, the CEPE models show an increase only in the case of electricity and biomass; fossil fuels and district heat will be decreasing in the Reference Scenario (see Table 12-8).

For the two mitigation scenario variants, there are some common characteristics in the development until 2050 (see Table 12-8): a substantial decrease in oil (-57 % and -66 % respectively in POLES, -85 % and -90 % in CEPE's models respectively). Also natural gas has a similar trend: In POLES, it decreases strongly in both mitigation variants (-56 % in the 450 ppm and -68 % in the 400 ppm variant), and also in CEPE's models natural gas demand is reduced considerably (-51 % in the 450 ppm variant and -87 % in the 400 ppm variant).

There are also some noticeable differences: Both fossil fuels and heat are reduced in CEPE's models, but in POLES, only fossils decrease. Biomass exhibits a marked increase in POLES by +169 % and +163 % respectively and but only a quite low increase in the case of CEPE's models (+21 % in both scenario variants). Also district heat also shows a quite different development: In POLES, it increases by +76 % to +69 % respectively, but in the CEPE models it decreases in all scenarios (Table 12-8). Since these shares in total final energy demand are in the order of 10 %, the deviation is understandable given the different absolute amounts of final energy demand in the two sectors. Similar structural differences are found regarding electricity, POLES still exhibits an increase of 45 % and about 60 % respectively (compared to 2005), whereas in CEPE's models, electricity demand is curbed by 15 % to 20 %. The differences are due in part to heat pumps, but also to the relative increase in electric appliances in the CEPE models due to the much lower heat demand assumed.

Table 12-8: Final energy of the residential and service sectors, in 2005 and 2050 (in EJ) and change between 2005 and 2050, EU27+2, Reference and 2°C Scenario

final energy	2005	Ref. Sc. 2050	450 ppm 2050	400 ppm 2050	Ref. Sc. 05/50	450 ppm 05/50	400 ppm 05/50
	POLES				**POLES**		
Fossil fuels	11.7	14.5	7.6	6.3	24%	-35%	-47%
District heat	1.5	2.6	2.7	2.6	69%	+76%	69%
Biomass	1.5	2.5	4.0	3.9	69%	+169%	163%
Electricity	5.6	9.9	9.5	9.0	78%	+70%	61%
TOTAL	20.4	27.0	21.2	19.2	33%	+5%	-5%
	CEPE				**CEPE**		
Fossil fuels	12.7	10.9	4.5	1.5	-14%	-65%	-88%
District heat	1.4	1.1	0.4	0.2	-21%	-73%	-84%
Biomass	1.0	1.1	1.2	1.2	17%	21%	21%
Electricity	5.8	8.4	4.7	4.8	44%	-17%	-18%
TOTAL	19.5	20.4	10.5	7.4	5%	-46%	-62%

Source: POLES' and CEPE results

To conclude, the final energy demand in the two variants of the 2°C Scenario projected by the POLES model is slightly reduced, but significantly curbed in the case of CEPE's models (by one half and about two thirds, respectively). All types of energy contribute to this difference, but in absolute terms, fossil fuels (-1.9 EJ and -4.8 EJ) and electricity (-3.4 EJ and -4.2 EJ) make the largest contribution by 2050 (see Table 12-8). The authors of the three HMS bottom-up models obviously assume a higher impact of energy and climate policies on the investments in energy efficiency and fossil fuel substitution than the authors of POLES. This relates to different assumptions about how much existing obstacles and market imperfection can be alleviated in the residential and service sectors.

12.4 Comparison of industry sector: POLES and ISIndustry

The development of CO_2 emissions is relatively similar in POLES and ISIndustry (see Figure 12-7). Both show a comparable downward slope, but where the POLES emissions path is constant until 2020, ISIndustry shows emission reductions from the first calculation year on. While for the 450 ppm scenario the final emissions level in 2050 is about one third higher in POLES than it is in ISIndustry, both models calculate very similar emission levels for the 400 ppm variant.

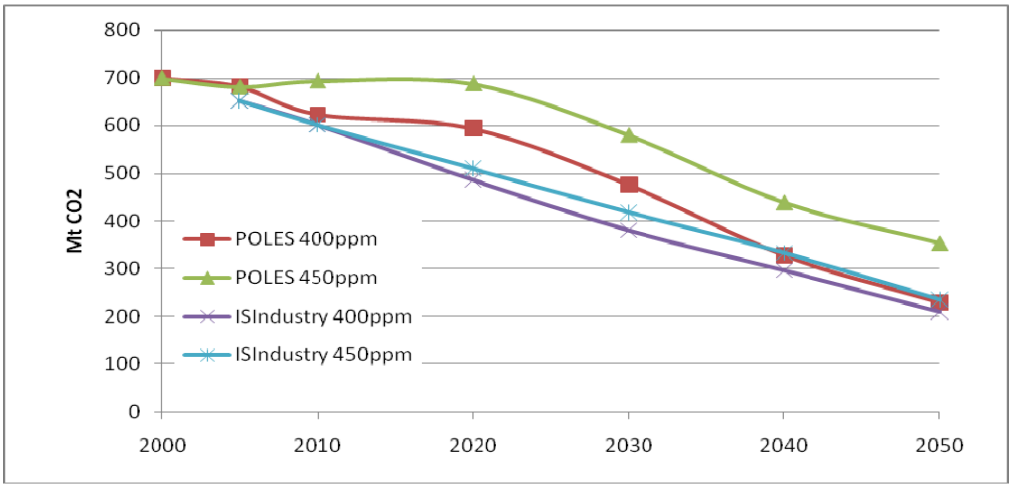


Figure 12-7: Comparison of industrial CO_2 emissions in POLES and ISIndustry for the 450 and the 400 ppm variant of the 2°C Scenario, EU-27+2, 2000 to 2050

The similarity of the development path for CO_2 emissions may give the impression that the models work in a similar way and thus projected a comparable reduction path. That this is not the case is shown in Figure 12-8. This plots the development of industrial final energy demand, which rises in the POLES 450 ppm variant to more than 18,000 PJ, but falls in ISIndustry to below 7,000 PJ. The difference is still marked in the 400 ppm variant, but not as much as in the 450 ppm variant, because emissions remain more or less constant in the 400 ppm case even in the 2°C Scenario of POLES. In ISIndustry, no difference between 400 and 450 ppm can be observed, which is due to the fact that the additional emission reductions between these two variants are mainly achieved by wide-scale deployment of solar heating technologies in industrial low to medium temperature processes (see Figure 12-8). Although solar thermal technologies reduce emissions considerably, they only have minor effects on the final energy demand as the share of thermal solar energy remains small until 2050.

These differing results are the effect of different assumptions about technological options for a sustainable industrial structure. While the reduction in CO_2 emissions in POLES is mainly achieved by a comprehensive fuel switch to renewables – mainly biomass – and deployment of CCS, ISIndustry develops a completely new industrial structure, which goes far beyond fuel switching and which will look very different to what is in place today. The steep decline in emissions in the ISIndustry calculations is based on a comprehensive material efficiency strategy that significantly reduces the demand for energy-intensive bulk products like steel, cement, paper, glass or aluminium (see section 5.2) and that is combined with the wide-scale diffusion of energy-efficient technologies and processes. Also Renewables and CCS play an important role in the ISIndustry scenarios, but less important than in the POLES calculations.

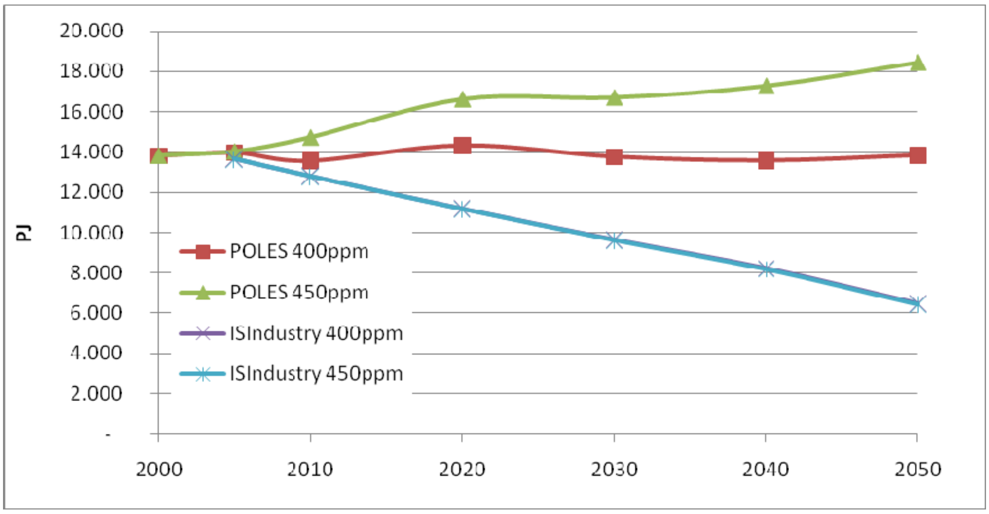


Figure 12-8: Comparison of industrial final energy demand in POLES and ISIndustry for the 450 and the 400 ppm variant of the 2°C Scenario, EU-27+2, 2000 to 2050

Further reduction effects come from the projected development of intra-industrial structural change in the sectors, which is a main input variable to the models. These show a structural change within many industrial branches for the ISIndustry towards higher value added per physical output. This assumption already significantly contributes to lower emissions in the Reference Scenario until 2050. As a consequence, even the projection of the production of energy-intensive industrial bulk products is lower in ISIndustry during the period until 2050 without assuming more material efficiency improvements.

12.5 Comparison of transport sector: POLES and ASTRA

12.5.1 Transport fuel consumption

This section compares the consumption of different fuel types in the transport sector as computed by POLES and by ASTRA on EU27 aggregated level.

The total transport fuel consumption within the EU27 in the Reference Scenario (Figure 12-9) calculated by POLES shows a roughly similar pattern to the fuel consumption computed by ASTRA. Both models show a fairly constant level of total fuel consumption over the entire simulation timeframe, with a peak in the first half. Both show a global peak around the same time, and then a drop by 2050. ASTRA peaks in 2014 at 16.3 EJ and POLES peaks in 2019 at 17.5 EJ. In ASTRA, total consumption then decreases by 10.4 % to 14.6 EJ in 2050. In POLES, fuel consumption drops by 10.8 % to 15.6 EJ in 2050. A more significant difference between the two models is the composition of the fuel types consumed. In 2000, ASTRA reports almost 100 % fossil fuels, while POLES already shows 2 % electricity consumption in the transport sector. In ASTRA, the fossil fuels are substituted by CNG & LPG (5 % in 2050) as well as by biofuels (7 % in 2050). In contrast, POLES calculates a share of 12 % electricity, 4 % biofuels and 3 % hydrogen in 2050.

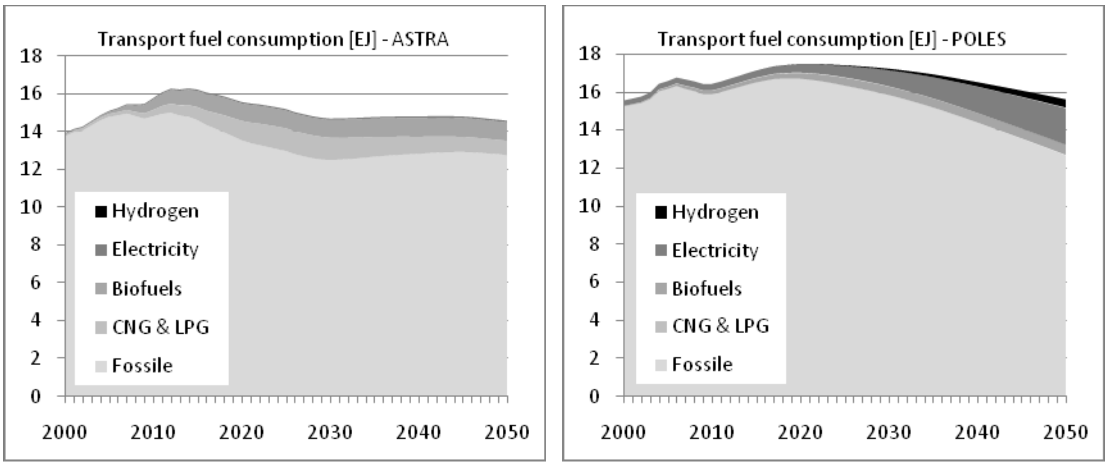


Figure 12-9: Transport fuel consumption in ASTRA and POLES for the Reference Scenario

In the 2°C 450 ppm scenario, the decline of the total transport fuel consumption in the EU27 is more pronounced in POLES than it is in ASTRA (Figure 12-10). In ASTRA, the total figure drops from 14 EJ in 2000 to 11 EJ in 2050, while in POLES, it falls from 15.6 EJ to 10.7 EJ for the same years. This represents a decrease of 21 % in ASTRA and 31 % in POLES. In both models, the composition of the total fuel consumption also changes compared to the Reference Scenario. In ASTRA, in 2050, fossil fuels account for 75 % of the total fuel consumption, biofuels for 13 %, CNG&LPG for 5 %, hydrogen around 4 % and the electricity share turns out to be 3 %. In comparison, POLES shows a stronger shift towards hydrogen along with a stronger reduction of fossil fuels, which account for 64 % of total fuel consumption. Electricity contributes around 20 %, hydrogen about 13 % and biofuels roughly 4 % of the total fuel consumption in this model.

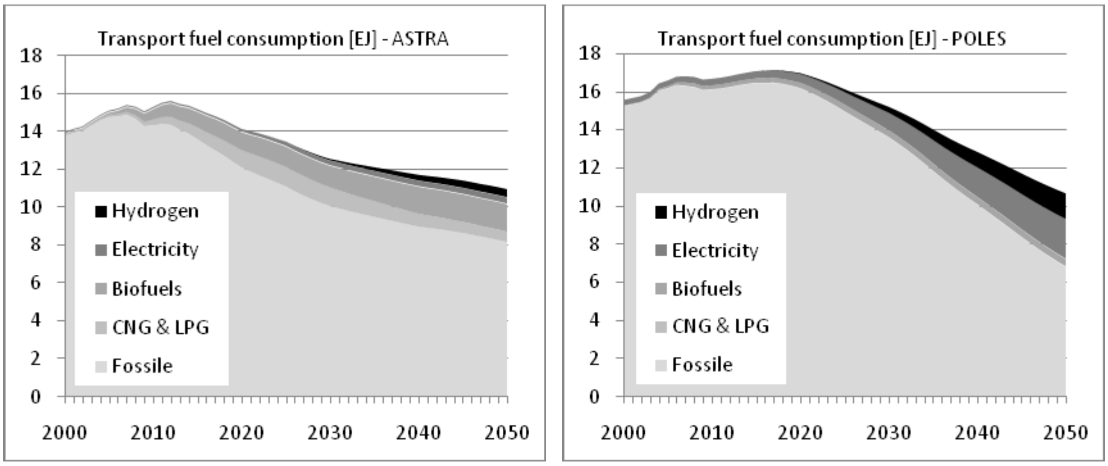


Figure 12-10: Transport fuel consumption in ASTRA and POLES for the 450 ppm scenario

In the 2°C 400 ppm scenario (Figure 12-11), ASTRA computes 8.3 EJ of total energy consumption within the EU27 in the transport sector, which is 24 % lower than the 450 ppm scenario and 43 % lower than the Reference Scenario. The fuels consumed shift away from fossil to alternative fuels with lower climate change impacts compared to the 450 ppm scenario. Fossil fuels contribute about 61 %, biofuels 21 %, electricity 8 %, hydrogen 5 % and CNG & LPG together also about 5 % of the total energy consumption in 2050. POLES indicates about 10.3 EJ of total energy consumption in 2050 for the 400 ppm scenario, which is only slightly smaller than the 450 ppm scenario, for which POLES computes 10.7 EJ. But the share of fossil fuels falls from 64 % in the 450 ppm variant to 60 % in the 400 ppm scenario. Biofuels remain at 4 %, but electricity increases significantly from 20 % in the 450 ppm scenario to 29 % in the 400 ppm scenario. The share of hydrogen in total transport energy consumption drops from 13 % in the 450 ppm scenario to 7 % in the 400 ppm scenario.

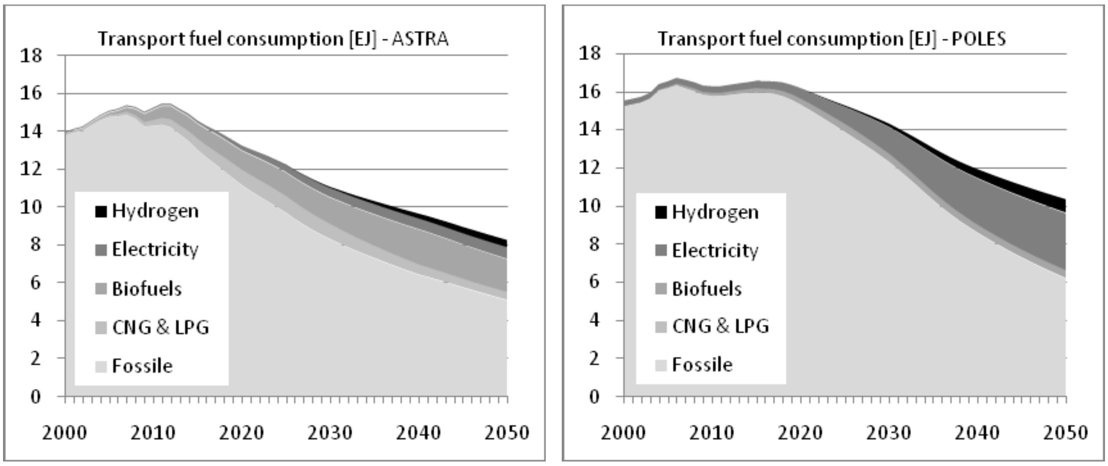


Figure 12-11: Transport fuel consumption in ASTRA and POLES for the 400 ppm scenario

12.5.2 Car Fleets

This section compares the composition of car fleets at EU27 aggregated level as computed by ASTRA and POLES. The car class “conventional” includes vehicles running on biofuels as well as on compressed natural gas.

The car fleets computed by ASTRA and POLES for the EU27 in the Reference Scenario (Figure 12-12) differ significantly in their composition. ASTRA assumes almost no alternative vehicle technologies on the market, with the exception of about 1 % of electric hybrid vehicles, while POLES assumes that electric, electric hybrid and hydrogen vehicles will significantly substitute conventional vehicles from 2020 on. According to POLES, in 2050, the European fleet will be composed of 27 % electric hybrid, 14 % electric, 10 % hydrogen and 50 % conventional vehicles.

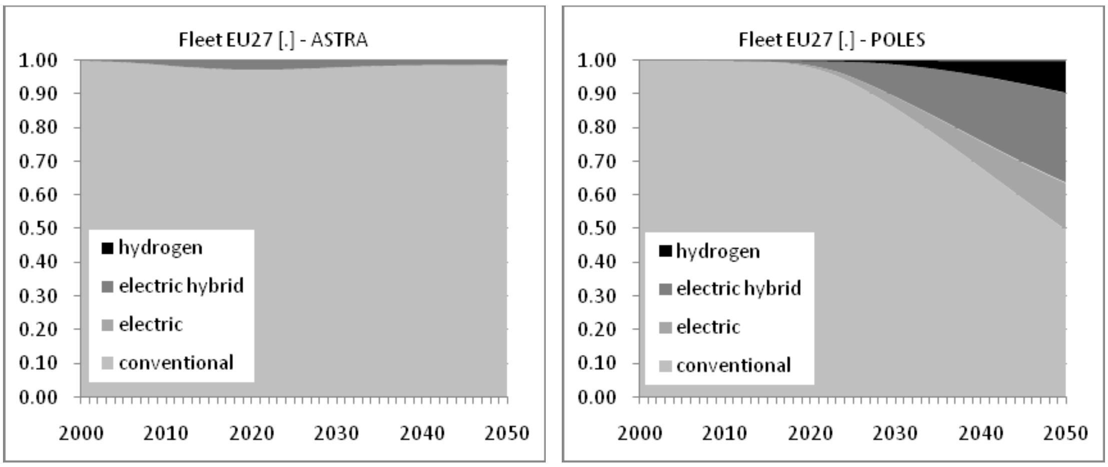


Figure 12-12: Car fleets in ASTRA and POLES for the Reference Scenario

For the 2°C 450 ppm scenario (Figure 12-13), ASTRA computes a significant introduction of electric and hydrogen vehicles. In 2050, about 9 % electric vehicles and 10 % hydrogen vehicles will be driven on European roads as well as 1 % advanced electric hybrid vehicles. However, 80 % of the total fleet will still be made up of conventional vehicles (including mild hybrids). For the same scenario, POLES calculates a stronger dissemination of the same technologies but already introduced in the Reference Scenario. In 2050, only 30 % conventional vehicles will remain on the roads. The total fleet will then be composed of 26 % electric, 34 % electric hybrid and 10 % hydrogen vehicles.

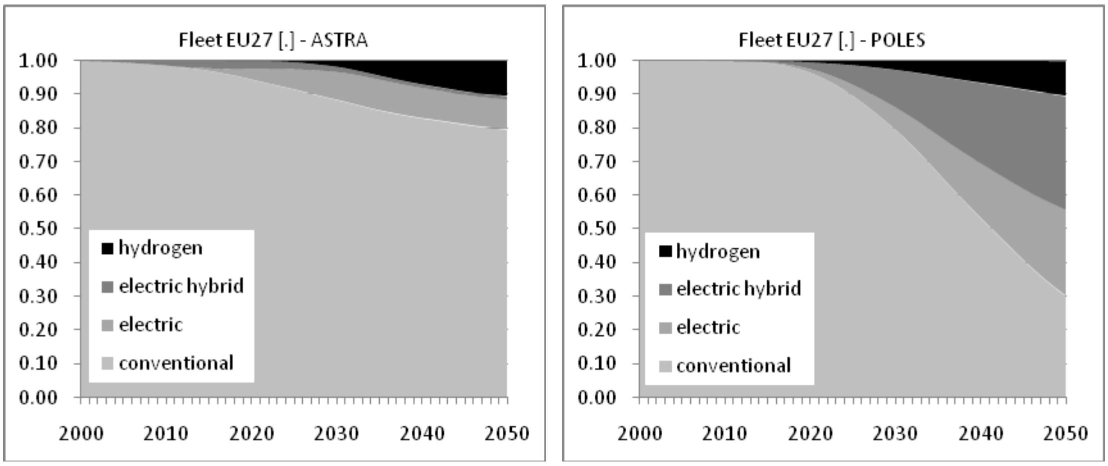


Figure 12-13: Car fleets in ASTRA and POLES for the 450 ppm scenario

For the 2°C 400 ppm scenario (Figure 12-14), both models come up with the most marked shift towards alternative vehicle technologies within the EU27. In ASTRA, efficient conventional vehicles will only make up 65 % of the total fleet in 2050, while 25 % of vehicles will be electric, 10 % hydrogen and 1 % equipped with an advanced hybrid electric drive train. POLES paints a very different picture: Conventional vehicles almost completely disappear from the roads, only making up 18 % of the total fleet, while 43 % are electric hybrid, 26 % electric and 14 % hydrogen vehicles.

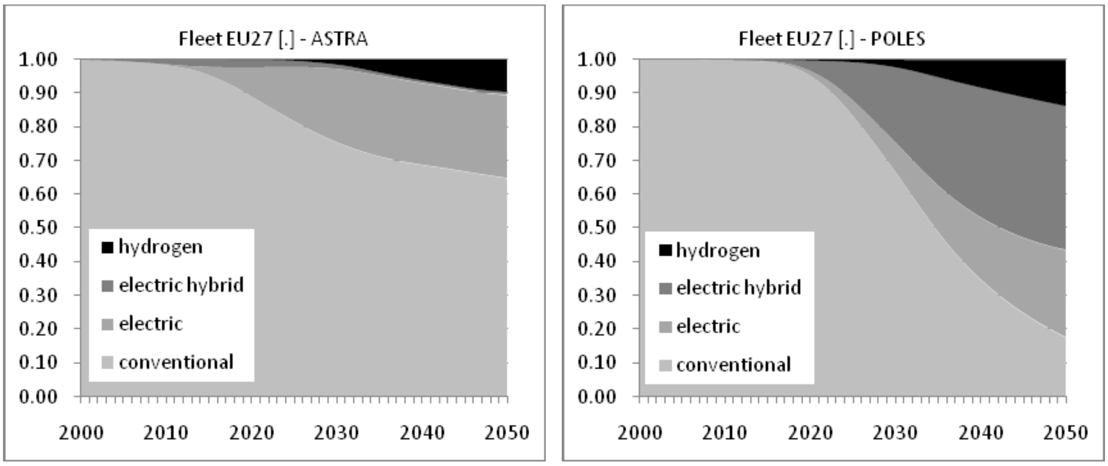


Figure 12-14: Car fleets in ASTRA and POLES for the 400 ppm scenario

The reasons for this difference are probably the moderate fuel price development provided by the ADAM scenario framework (see section 2), which seems rather optimistic, and the significantly lower CO_2 prices in ASTRA compared with POLES. The result is that neither fuel prices and oil scarcity nor high CO_2 prices push fossil-fuelled cars off the roads in ASTRA while this does occur in POLES as a consequence of the high carbon values (see Figure 12-1).

12.6 Comparison of renewables sector: POLES and PowerACE-ResInvest

The use of renewable energy sources in the electricity sector is modelled on the one hand by PowerACE-ResInvest, focussing exclusively on the renewables sector, and on the other hand by the POLES model, which covers the predominant part of the power sector as a whole.

12.6.1 General comparison of modelling approach and assumptions

Both models differ with regard to the RES technologies included and the corresponding level of aggregation (see Table 12-9). In general, renewables are displayed in greater detail within PowerACE-ResInvest than in POLES, but POLES includes modelling of the non-biogenic fraction of municipal solid wastes. Geothermal electricity, solar thermal electricity and ocean energy are considered within PowerACE-ResInvest, but are not included in the POLES model.

Table 12-9: Renewable conversion technologies covered by POLES and PowerACE-ResInvest

	POLES	PowerACE-ResInvest
RES-technology	**covered**	**covered**
Wind-Onshore	yes	yes
Wind-Offshore	yes	yes
Solar PV	yes	yes
Solar Thermal Electricity	no	yes
Geothermal Electricity	no	yes
Hydro power (large scale)	yes	yes
Hydro power (small scale)	yes	yes
Solid biomass plants	yes	yes
Biogenic MSW plants		yes
Non-biogenic MSW plants		no
Agricultural biogas plants	yes	yes
Landfill gas plants		yes
Sewage gas plants		yes
Wave energy	no	yes
Tidal stream energy	no	yes

POLES and PowerACE-ResInvest also follow different modelling techniques. Although both are simulation models, POLES includes inter-technology competition, whereas the PowerACE-ResInvest simulation focuses on the RES market and includes influences of the conventional power sector in the form of exogenous inputs such as electricity prices or electricity demand. POLES is based on the principles of a dynamic Partial Equilibrium Model with a dynamic simulation process, whereas the PowerACE-ResInvest logic is based on individual agents deciding whether an investment in renewable technologies is profitable or not. The investment decisions of the agents are based on a net present value calculation taking into account cost potential curves, which provide information about the available national potential to exploit RES and the involved electricity generation costs.

12.6.2 Specific comparison of the 2° Scenario results

Both models pursue different strategies concerning the policy support for RES. Whereas POLES assumes that the main support for renewables comes from the impact of the price on carbon on the competitiveness of RES technologies, PowerACE-ResInvest assumes additional support to be active in terms of the currently existing technology support schemes. Since conversion technologies using RES are generally not competitive with conventional resources at present, the assumed financial policy support represents one of the crucial drivers for RES-development, in particular during the first half of the modelling period. As PowerACE-ResInvest does not consider inter-technology competition with non-renewable conversion technologies, the impact of the carbon value is taken into account indirectly by assuming financial support to be available for renewable energy technologies. This support level is calculated based on the economic value of CO_2 that can be avoided by the use of low-carbon technologies (see Section 10.3.1).

The two models show different outcomes concerning RES in particular towards the end of the period as a result of the different underlying modelling techniques and assumptions (see Figure 12-15). During the first five modelled years (2005 to 2010), both models show a similar trend of RES-E development. As the increasing carbon price appears to be insufficient to stimulate more growth of RES-E technologies up to 2040, the POLES model projects a steadier growth in RES-E technologies than PowerACE-ResInvest. In the PowerACE-ResInvest model, additional technology-specific support instruments promote earlier investment in RES-E conversion technologies. Starting in 2040, the RES-E development projected by POLES accelerates as a consequence of the increasing carbon price. Another reason for the differences in the results is the slightly diverging technology coverage (compare with Table 12-9). Whereas Poles predicts a slightly different development of RES in the 400 ppm scenario and the 450 ppm scenario, PowerACE-ResInvest assumes the same RES development in both scenarios.

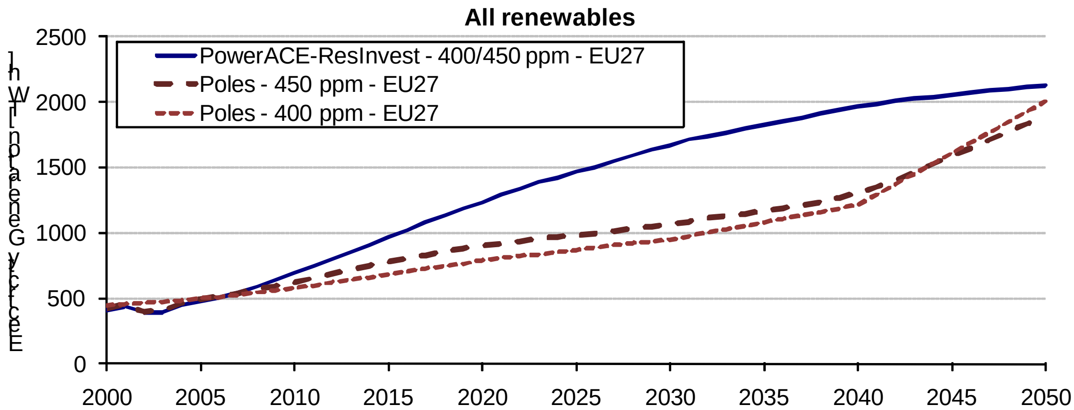


Figure 12-15: Comparison of modelling results – renewable electricity generation in the EU up to 2050 projected by PowerACE-ResInvest and POLES (2° Scenario)

The predicted development of wind onshore & offshore in the 2° Scenario diverges considerably due to the different policy assumptions made in each model. Wind power development is triggered by technology-specific support schemes such as feed-in tariffs as well as the impact of the carbon value (see sections 4 and 10). In addition, the potentials considered to be available for the use of wind power differ between the models.

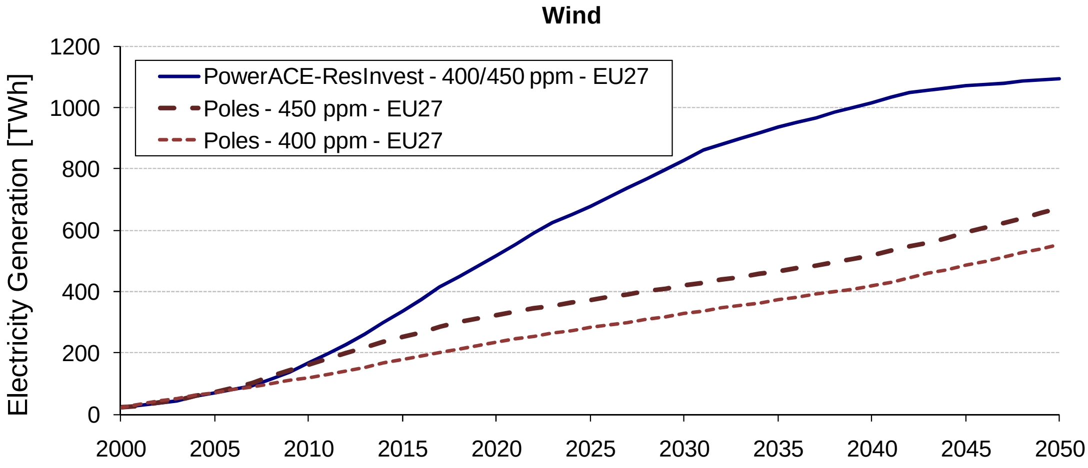


Figure 12-16: Comparison of modelling results – wind electricity generation in the EU up to 2050 projected by PowerACE-ResInvest and POLES (2° Scenario)

With regard to the evolution of solar electricity, the results of both models show a comparable development up to 2035. It should be noted that the PowerACE-ResInvest results comprise the development of solar thermal electricity in Mediterranean countries, whilst POLES focuses exclusively on the development of solar photovoltaics (PV). In PowerACE-ResInvest, the share of concentrating solar power (CSP) reaches 23 % by 2050. POLES shows a faster development of PV-devices in the 450 ppm Scenario which begin to take off around 2035, whilst the development of PV in the 400 ppm Scenario remains moderate. This might be explained by the significantly stronger use of biomass in the 400 ppm Scenario, which substitutes solar electricity generation in the 450 ppm Scenario.

The reason for the observed differences is the difficulty in predicting PV-development due to the high degree of uncertainty about achievable future cost reductions. Compared to other RES, PV is a cost-intensive way to generate electricity , but it has the advantage of decentral installation. Therefore, PV development strongly depends on whether PV electricity is priced at wholesale or retail prices.

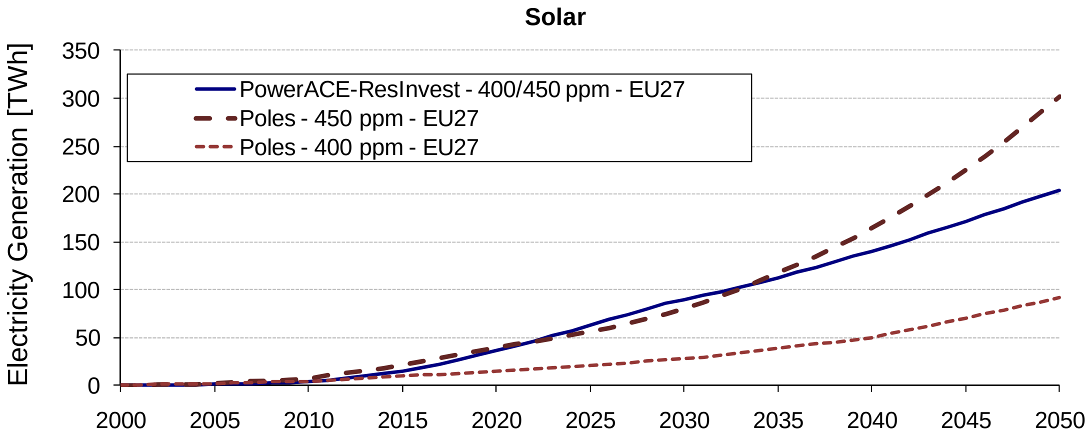


Figure 12-17: Comparison of modelling results – solar electricity generation in the EU up to 2050 projected by PowerACE-ResInvest and POLES (2° Scenario)

Electricity generation using biomass, biowaste and biogas shows a very moderate development up to 2040 in the POLES model and then increases strongly, whereas PowerACE-ResInvest indicates earlier investments in biomass conversion technologies and a slowdown towards the end of the modelling period. Similar to the evolution of wind onshore, the observed differences can be attributed to differing policy assumptions.

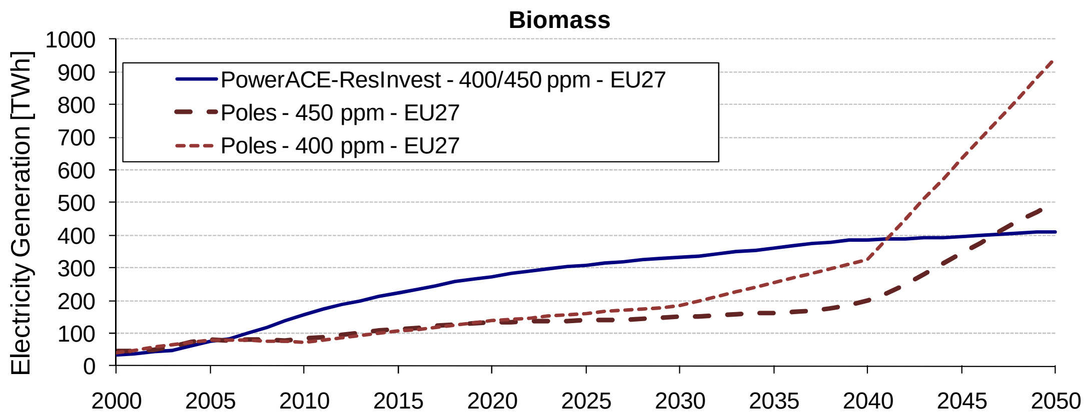


Figure 12-18: Comparison of modelling results – biomass electricity generation in the EU up to 2050 projected by PowerACE-ResInvest and POLES (2° Scenario)

12.7 Comparison of conversion sector: POLES and EuroMM

The European Markal model EuroMM describes the energy conversion sector in Europe, combining least-cost analysis of the energy supply side with the inputs from other bottom-up models for final energy demands. The differences between this modeling approach and the POLES model have been described earlier (Jochem et al. 2007) and are not further discussed here. However, it is important to mention that both models use the same assumptions about costs and efficiencies for most of the technologies regarding electricity generation. In the following, the main results for primary energy demand and electricity generation are compared.

12.7.1 Primary energy

Primary energy demand in EuroMM is approx. 25 % to 30 % lower in 2050 compared to the results in POLES for the 450 ppm and 400 ppm scenarios (see Figure 12-19). In addition, the primary energy demand in EuroMM peaks around 2010, and around a decade later in POLES. These differences mainly occur due to the assumptions about final energy demands which are compared in sections 12.3-12.5. However, some differences can also be explained by the results for the energy supply sector, mainly electricity generation, where fossil fuels play a more important role in the POLES model (see section 12.7.2 and further discussion below).

One aspect of primary energy is the availability of biomass for energy purposes. In both EuroMM and POLES, a biomass potential of approx. 8 EJ is assumed for 2005. Until 2050, this potential can be extended and reaches 10.2 EJ in POLES and 12.8 EJ in the 400 ppm scenario in EuroMM. Additional biomass imports from other world regions for energy purposes vary between the two models. POLES assumes biomass imports of approx. 9.6 EJ in 2050 in the 400 ppm scenario, while EuroMM shows imports of 2.6 EJ for the same scenario. Other main differences in the results concern the use of biomass for biofuel and hydrogen production. While in POLES a high share of hydrogen is produced from biomass and the biofuel demand in transportation is low, in EuroMM the biomass is used for biofuel production and hydrogen is produced primarily via electrolysis using wind electricity. The differences between POLES and the ADAM-HMS regarding biofuel in transportation is further explained in section 12.5.

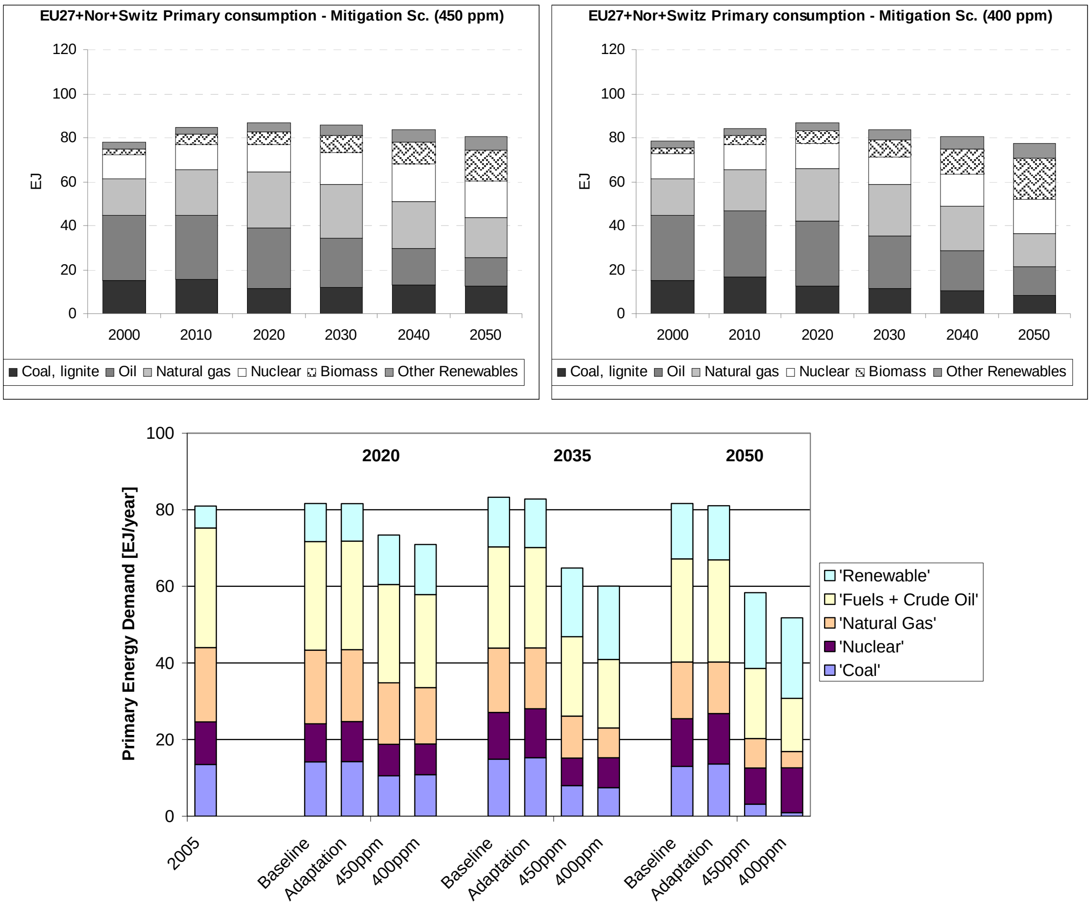


Figure 12-19: **Comparison of results between POLES (top) and EuroMM (bottom) for primary energy demand**

12.7.2 Electricity generation

In the electricity sector, there are a number of differences between EuroMM and POLES regarding the output of power plants. One of the most notable differences is that total electricity output is 50 % to 60 % higher in 2050 for POLES compared to EuroMM for the 450 ppm and 400 ppm scenarios, again because of the differences in final energy demands discussed in sections 12.3-12.5. While the POLES results show a high share of fossil fuel based electricity generation (up to 40 %), EuroMM shows an almost CO_2-free electricity sector. It is noteworthy that the output of renewable electricity in both models is in the range of approx. 2000TWh in 2050 in the 450 ppm and 400 ppm cases. The output for nuclear electricity is slightly higher in the POLES results. However, because total generation is significantly lower in EuroMM, the share of renewable and nuclear electricity is higher in EuroMM. For instance, in EuroMM, almost 75 % of total electricity generation is based on renewable fuels, whereas POLES estimates a share of approx. 30 %. This difference may be partly related to different assumptions regarding the integration of intermittent renewable sources of generation. Specifically, EuroMM presents scenarios where electricity grid management and trade facilitate a high penetration of intermittent renewables. In contrast, the POLES results, with the lower share of renewables, illustrate the implications of being unable to integrate a large amount of intermittent renewable resources, in which case fossil fuels (with carbon capture and storage) need to play a much larger role in the energy system. This represents a potentially important key uncertainty requiring further analysis to determine the most suitable technology options for mitigation.

Despite these differences, the other main explanation for the differences in results is again the different assumptions about demands. In this respect, it is also necessary to further evaluate and understand the drivers behind the demand scenarios.

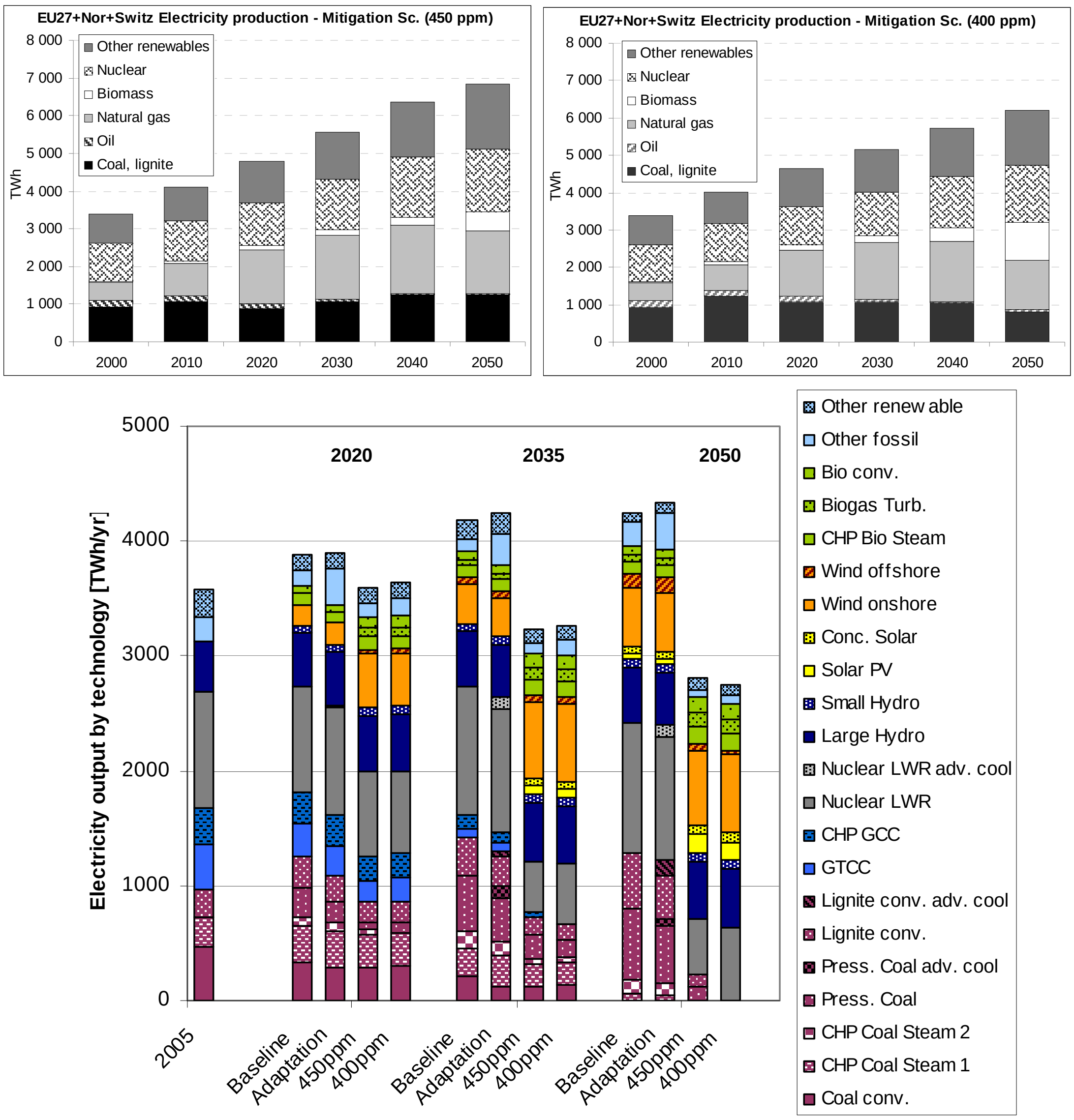


Figure 12-20: **Comparison of electricity generation between the POLES model (top) and EuroMM (bottom)**

12.8 Summary of bottom-up analysis

The broad message of the sectoral analyses performed for Europe using the ADAM-HMS and the POLES models is congruent: A pathway to reach the 2°C target is technologically feasible. However, there is no silver bullet in climate policies; many or even all the wedges of emission reductions will have to be forcefully activated and over a longer time horizon. A broad package of policies to stimulate technological change as well as behavioural change has to be implemented by the EU, the Member States and municipal governments.

In the details of how and when, the two analyses provide mostly congruent, but also partially divergent answers. The reasons for divergence must be looked for in the different expectations of how barriers to implement technologies can be overcome. Such barriers could be technological, cost or acceptance barriers, which require different approaches to overcome them. Thus the results of the two analyses are presented as two possible storylines of how to reach the 2°C target.

The baseline for both storylines is that carbon, or in a wider sense, GHG emissions, have to be given a price, either in the form of an ETS or a carbon tax. However, such a policy on its own does not seem to be sufficient since (1) the price signals of an ETS in the first decades would be too low to stimulate sufficient policy support for new technologies and sufficient behavioural change to implement sectoral policies. (2) Pricing systems are intended to affect markets, but markets in general apply a short-term perspective, looking at short-term rates of return and short-term break-even points, while the system transitions necessary for climate policy require a long-term perspective and can only be implemented over a long time horizon. Thus giving carbon a price has to be accompanied by sectoral policies that forcefully stimulate new technologies and behavioural change from now until 2050.

12.8.1 The ADAM-HMS storyline of the 2°C scenario

The four major building blocks of the ADAM-HMS 2°C scenario storyline include:

- immediate action,
- energy efficiency,
- renewables and
- materials efficiency and structural change.

Immediate action implies that, from 2010 onwards, climate policies have to start fostering the improvement of efficiency in all sectors (residential, industry, services, transport, energy conversion) and must do so at a relevant pace in order to achieve an annual reduction of final energy demand of close to -1 % despite moderate demand growth in the final energy sectors in the next decade. This reduction should then increase annually in the following decades. In terms of annual CO_2 reduction rates, these have to be close to --2 %. A failure to achieve immediate reductions will mean that in later years the annual reductions of CO_2 emissions, already amounting to -4 to -5 %, will have to be even higher (about 1 to 3 % more, annually).

The second major building block of this storyline is energy efficiency improvement in all sectors. The burden of improvement is similar in all final energy sectors. Transport, industry and residential/services have to reduce their final energy demand by about -1.6 % annually from now on until 2050. This is an ambitious target, which requires that improving energy efficiency has to be treated as a cross-cutting technology and a strategic approach that is followed by all the stakeholders in business, households and policy-making. Of course, not only climate policy exerts pressure on improving energy efficiency. Energy security and the depletion of fossil fuels (which will be relevant in the next 30 to 40 years) also constitute two major drivers of energy efficiency.

The third major building block to achieve the 2°C scenario comprises renewables, in particular used for electricity generation, but also for heating and biofuels for transport. In 2050, about 75 % of electricity generation will be based on renewables and about 20 % of transport fuels will be biofuels. One should consider that the percentage numbers refer to a relatively low final energy demand due to the efficiency improvements. Major national studies indicate that even levels of more than 80 % renewables for electricity production could be achieved until 2050, e.g. in Germany [Nitsch 2008].

The fourth building block is increased materials efficiency and structural change. Due to improvements in materials efficiency, for example, the demand in specific sectors will be reduced (e.g. steel production shifting to high strength steel). This contributes to reductions of energy demand as well as fostering structural production changes, e.g. when new materials are introduced like compound materials replacing steel.

On the other hand, two major elements that are considered in other 2°C scenarios play a very limited role here. First, nuclear electricity production remains roughly stable until 2050, and plays only a limited role in reducing GHG emissions. Second, carbon capture and sequestration (CCS) is not required by the electricity sector at all because only very limited fossil energy will be used in 2050 (<10 % of electricity production), which can be generated by highly efficient fossil plants without the need for CCS.

12.8.2 The POLES storyline of the 2°C scenario

The three major building blocks of the POLES 2°C scenario storyline include:

- increased use of electricity,
- high use of biomass, and
- substantial use of carbon capture and storage technologies (CCS).

The first major block in POLES is the marked increase in electricity demand until 2050. Between 2010 and 2050, electricity demand increases by about +50 %, which is double the demand of the ADAM-HMS in the 400 ppm scenario. This can be explained by the electrification of the energy sector since the overall energy demand in POLES is slightly reduced. The other two major building blocks fit this picture and contribute to the CO_2 reductions in POLES together with electrification.

The second building block is the increased use of biomass also involving a significant amount of imported biomass of close to 10,000 PJ in 2050. The third building block is CCS, which enables about 65 % of the remaining CO_2 emissions to be stored in 2050. If CCS is combined with biomass, it may even be possible in 2050 for electricity generation to have a negative net CO_2 balance, i.e. more CO_2 is saved than emitted.

Improved energy efficiency makes a limited contribution in this storyline, although final energy demand is reduced by -15 % until 2050. The POLES model simulations do not focus on improved material efficiency or structural change.

12.8.3 Policy conclusions from the bottom-up analyses

The main policy conclusions that should be drawn from the two bottom-up analyses can be summarised by the following list of bullet points:

- Assigning carbon (or GHGs) a price is a major pre-requisite for successful climate policy, as it translates the environmental constraints into a market signal. However, this is only a necessary pre-requisite, not a sufficient stand-alone instrument to achieve the 450 or 400 ppm targets.
- Implement a coherent set of policy measures such to overcome barriers that prevent investments in cost-effective and low-cost energy-efficiency measures and renewable energies: codes and standards including MEPS, preferential loans and other financial instruments, labels and other information measures. Ultimately temporarily limited subsidy schemes that could be financed by a carbon levy might be necessary to achieve underlying ambitious assumptions.

- New technologies play a very important role in achieving the goals of ambitious climate policy. Thus massive investments for public and private R&D are required for efficiency technologies (e.g. new insulation materials and highly efficient building technologies including controls for buildings, highly fuel-efficient vehicles, new engine technologies, CO_2 lean industrial processes), renewables and, to limited extent, also CCS.
- The take-up of low carbon technologies by the markets has to be accelerated. This should be achieved by norms, standards and labels wherever appropriate, e.g. in buildings, vehicles or power plants. The second effect of norms and standards is that they provide certainty for investors who plan for investments requiring a long-term payback period.
- Foster the system transition of urban structures considering (1) that more than 50 % of persons live in urban areas and their share will grow [UNFPA 2008]; (2) the integrated development of city structures and transport infrastructures reduce the need for motorized transport and pave the way for new forms of mobility (e.g. car- and bike-sharing, electric city and delivery vehicles, barrier-free, multi-modal transport); (3) the creative potential of urban areas attracts qualified and young/innovative groups of people.
- Take immediate action since each year lost before shifting the transition pathway towards a low carbon society represents a year requiring even stronger action in the subsequent years.

13 Macro-economic impacts of climate policy in the EU

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In this section the macro-economic impacts of the mitigation measures in the 2-degree scenarios described in the previous sections 5 to 12 are assessed for Europe. The assessment is based on the economic modules of the ASTRA model i.e. the *macroeconomics module* (MAC) and the *foreign trade module* (FOT) of ASTRA. The economic results are compared with the Reference Scenario i.e. a scenario in which adaptation and damages to the capital stock occured, which do not occur in the 2-degree scenarios, as the policy is assumed to avoid such climate damages. The Reference Scenario and its economic impacts have been described in our deliverable D2 of work package M1 [Jochem et al. 2009]. The analysis neglects the financial crisis happening in the years 2008 and 2009, though it already applies low GDP growth rates compared with many other studies (e.g. annually +1.8 % from 2010 until 2020 and +1.6 % from 2020 until 2030 for the EU27). A complementary analysis of the potential impacts of the financial crisis on mitigation efforts is presented in the following section 14 applying the E3MG global economic model.

This chapter is structured into five main section s. It starts with a brief description of the economic model structure of the ASTRA model (section 13.1) followed by an explanation of how the impulses of the bottom-up models enter the ASTRA model (section 13.2). Thirdly, the aggregate bottom-up impulses are presented i.e. the mitigation investment, the changes of energy expenditures and energy imports, the required subsidies and programme cost (section 13.3) followed by the analysis of the macro-economic impacts of the 2-degree scenarios for the EU (section 13.4). The final chapter concludes the economic analysis of the 2-degree scenarios for Europe (section 13.5).

13.1 Structure of economic models of ASTRA

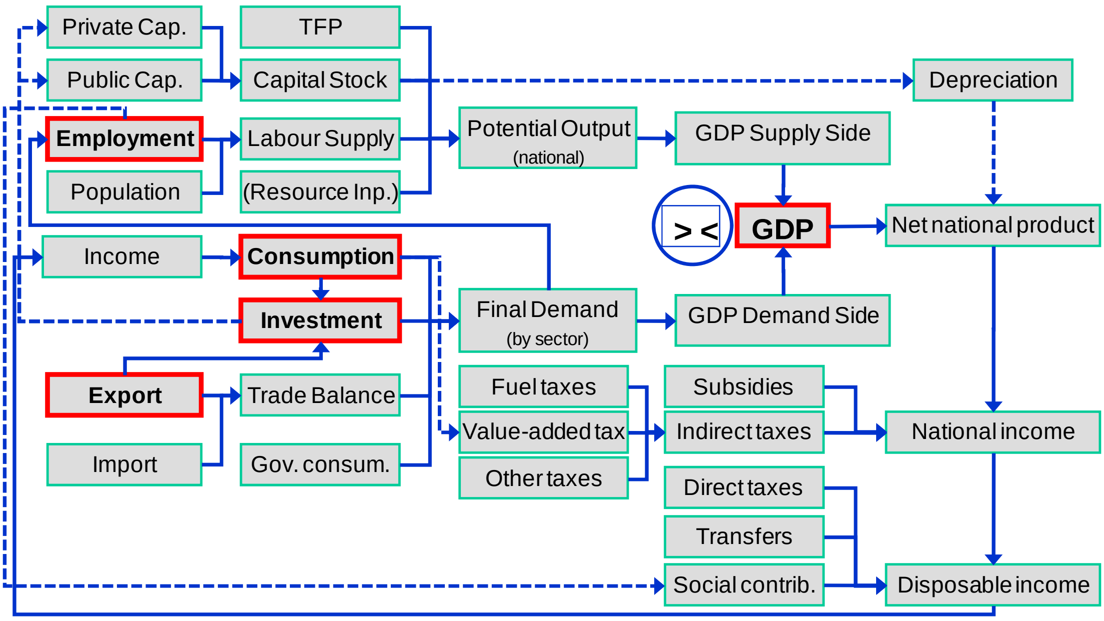
ASTRA stands for Assessment of Transport Strategies. The model has been continually developed since 1997 and is used for the strategic assessment of policies in an integrated way, i.e. by *considering the feedback loops between the transport system and the economic system*. Since 2004, it has been further extended by a number of studies and linked with energy system analysis, e.g. to analyse the economic impacts of high oil prices [Schade/Fiorello et al. 2008], the economic impacts of the European renewables strategy [Ragwitz/Schade et al. 2009] and of the German climate strategy [Jochem/Jäger/Schade et al. 2008]. The structure of the transport models in ASTRA has been explained in section 9 as ASTRA in the ADAM project is also applied to undertake the bottom-up analysis of the transport sector.

The model is based on the System Dynamics methodology similar to the POLES model (described in section 4), which can be seen as a recursive simulation approach. It follows system analytic concepts which assume that the real systems can be conceived as a number of feedback loops that are interacting with each other. These feedback loops are implemented in ASTRA and the model is calibrated for key variables for the period 1990 until 2003/2006. The spatial coverage extends over the EU27 countries plus Norway and Switzerland. Each country is further disaggregated into a maximum of four functional spatial zones based on their settlement characteristics and classified into metropolis zones, high-, medium- and low-density zones. A detailed description of ASTRA can be found in Schade [2005] with extensions described in Krail et al. [2007].

The ASTRA model consists of nine modules that are all implemented within one Vensim system dynamics software file:

- Population module (POP),
- Macroeconomic module (MAC),
- Foreign trade module (FOT),
- Regional economic module (REM),
- Infrastructure module (INF),
- Transport module (TRA),
- Environment module (ENV),
- Vehicle fleet module (VFT) and
- Welfare measurement module (WEM).

As the transport modules have been explained in section 9, the following descriptions focus on the presentation of the economic modules, i.e. MAC and FOT. An overview of the major interactions within the economic modules is given in Figure 13-1. Core variables of the economic models have been highlighted, which are consumption, investment, exports and employment that are all calculated in the level of 25 economic sectors by country as well as GDP, calculated on the national level taking into account both the behaviour of GDP on the supply side (i.e. driven by capital stock, labor supply and total factor productivity (TFP)) and on the demand side (i.e. driven by the behaviour of consumption, investment, government and the trade balance). The description of the structure of the 25 economic sectors is presented in Annex 16.3.



Source: ADAM-M1, Fraunhofer-ISI

Figure 13-1: Overview on the structure of the ASTRA economic models

The economic models implemented in ASTRA reflect the view of the economy as constructed of several interacting feedback loops (e.g. income – consumption – investment – final demand – income loop, the trade – GDP – trade loop etc.). These feedback loops are comprised of separate models which do not refer to only one specific economic theory. For instance, investments are partially driven by consumption following Keynesian thought, but exports are added as a second driver of investment. Neoclassic production functions are used to calculate the production potential of the 29 national economies (i.e. the potential output). Total factor productivity (TFP) is endogenised following endogenous growth theory by considering sectoral investment and freight travel times as endogenous drivers of TFP.

The macroeconomics module (MAC) provides the national macroeconomic framework and constitutes the core ASTRA module, which is needed for the economic assessment of the mitigation policy. The macroeconomics module is made up of six major elements. The first is the sector interchange model that reflects the interactions between 25 economic sectors of the 29 national economies. This is done by implementing an input-output table into the MAC. Demand-supply interactions are considered by the second and third element. The second element, the demand side model, depicts the four major components of final demand: consumption, investments, exports-imports and government consumption.

The supply-side model reflects the influence of three production factors: capital stock, labour and natural resources as well as the influence of technological progress that is modelled as total factor productivity. Endogenised Total Factor Productivity (TFP) depends on sectoral investments, freight transport times and sectoral labour productivity changes weighted by sectoral value added. Investments are involved in a major positive loop since they increase the capital stock and total factor productivity (TFP) of an economy which leads to a growing potential output and GDP that in turn drive income and consumption which feeds back into an increase of investments again. However, this loop may be influenced by other interfering loops that could disrupt the growth tendency. Examples of such loops are:

- In ASTRA, the existence of the 'crowding out' effect is accepted so that increasing government debt could have a negative impact on investment.
- Exports, e.g. influenced by mitigation policy, energy and transport cost, can also change, which in turn would affect investments.
- Different growth rates between the supply side (potential output) of an economy and the demand side (final demand) change the utilisation of capacity. If demand grows slower than supply, utilisation would be reduced which would also have an effect on investment decisions. Ultimately, investments could decrease.
- Substantial changes of energy prices could cause inflation, thus reducing real disposable income.

The employment model constitutes the fourth element of MAC based on value-added as the output from the input-output table calculations and labour productivity. The fifth element of MAC describes government behaviour. As far as possible government revenues and expenditures are differentiated into categories that can be modelled endogenously by ASTRA and one category covering other revenues or other expenditures. Categories that are endogenised include VAT and fuel tax revenues, direct taxes, import taxes, social contributions and revenues of transport charges on the revenue side as well as unemployment payments, transfers to retired persons and children, transport investments, interest payments on government debt and government consumption on the expenditure side.

The micro-macro bridges form the sixth and final element comprising the MAC. These link micro- and meso-level models of ASTRA, for instance the transport module or the vehicle fleet module to components of the macroeconomics module. This means that expenditures for bus transport or rail transport of one origin-destination pair (OD) become part of the final demand of the economic sector for inland transport within the sectoral interchange model. This element also includes the linkages with the bottom-up models of the ADAM hybrid model system (ADAM-HMS).

The Foreign Trade Module (FOT) is divided into two parts: trade among the EU27+2 European countries (INTRA-EU model) and trade between the EU27+2 European countries and the rest-of-the world (RoW) that is divided into fifteen regions (EU-RoW model with, Arab-African Oil Exporters, Asian Oil Exporters, Brazil, China, East Asia, India, Japan, Latin

America, North America, Oceania, Russia, South-Africa, South-Asia, Turkey, Rest-of-the-World). Both models are differentiated into bilateral relationships by country pair and sector.

The INTRA-EU trade model depends on three endogenous and one exogenous factor. World GDP growth exerts an exogenous influence on trade. Endogenous influences are provided by: GDP growth of the importing country of each country pair relation, the relative change of sectoral labour productivity between countries and the averaged generalised cost of passenger and freight transport between countries. The latter is chosen to represent an accessibility indicator for transport between countries. In the ADAM-HMS in particular the changes of trade patterns of fossil energy is provided from the bottom-up models to the ASTRA trade model.

The EU-RoW trade model is mainly driven by the relative productivity between the European countries and the rest-of-the-world regions. Productivity changes together with GDP growth of the importing RoW-country and world GDP growth drive the export-import relationships between the countries. In principle, ASTRA could exogenously consider first mover advantages of the EU in the case of ambitious mitigation policies of Europe. This was not assumed in the ADAM project, as it is expected that other regions have to implement similar ambitious mitigation policies and thus also develop their carbon lean industries. The resulting sectoral export-import flows of the two trade models are fed back into the macroeconomics module as part of final demand and national final use, respectively.

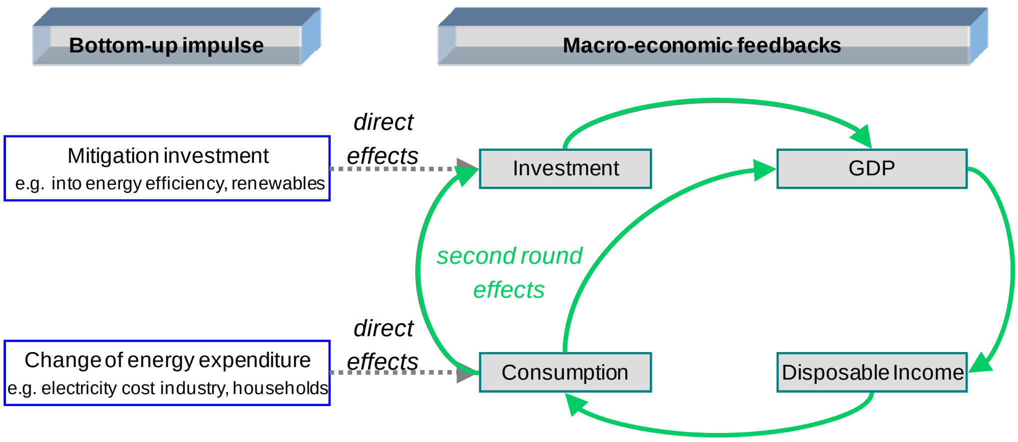
The purpose of the ASTRA model is to analyse long-term and strategic developments. Thus the model concentrates on describing the real economy and to a large extent neglects the short-term oscillations caused by the financial system. Two effects related to the financial markets are considered in ASTRA: (1) crowding out of private investment due to increased government debt and thus increased interest rates, and (2) dampening impact of inflation on real disposable income induced by higher energy prices. Both impacts were of limited importance in the ADAM analyses as the policies do involve only limited government mitigation investments besides private investment and as the energy efficiency increases rather tend to reduce energy expenditures instead of increasing them.

The economic outcome of the mitigation policies in the different countries depends on the countries' specific characteristics with respect to renewable potentials, adaptation impacts, current energy use as well as their specific economic characteristics which are reflected either in the ASTRA model or in the bottom-up inputs into ASTRA. Among the important characteristics are:

- The existing energy system and the cost of energy in a country.
- The elasticity of consumers and industry in responding to energy price changes or changes of the CO_2 prices.

- The level of (un-)employment which affects the reaction of the labour market.
- The productivity effect of investments in mitigation technologies compared with the productivity effect of other investments.
- The inter-industry structure, in particular the input-output relations of the energy sector and the major sectors producing mitigation technologies, i.e. machinery, electronics, construction, computers and metal products.
- The trade relationships among EU countries, i.e. growth in one EU country can lead to growth in other countries via imports.
- The competitiveness to export technologies for climate mitigation.
- The potential to produce biomass and use other renewable energies.

All these characteristics shape the indirect effects in the national economies that are triggered by the direct effects that are caused by the mitigation policies implemented for the 2-degree scenarios in the eight bottom-up models of the ADAM-HMS and then transferred to the ASTRA model. Figure 13-2 presents the conceptual structure of how bottom-up impulses (i.e. direct effects) feed into ASTRA. Two examples of such bottom-up impulses are (1) the investment into energy efficiency or renewables and (2) the change of energy expenditures of households implementing energy efficiency technologies in buildings. The former enters the economic models as a direct effect on the investment variable, the latter as a direct effect on the consumption variable. In the first round of model simulations this would lead to a change of GDP and the disposable income, which then feeds back onto the consumption variable and the investment variable, and the impacts would lead to a second round of changes of GDP, income etc. Thus one speaks of the second round (or indirect effects) of the mitigation policies

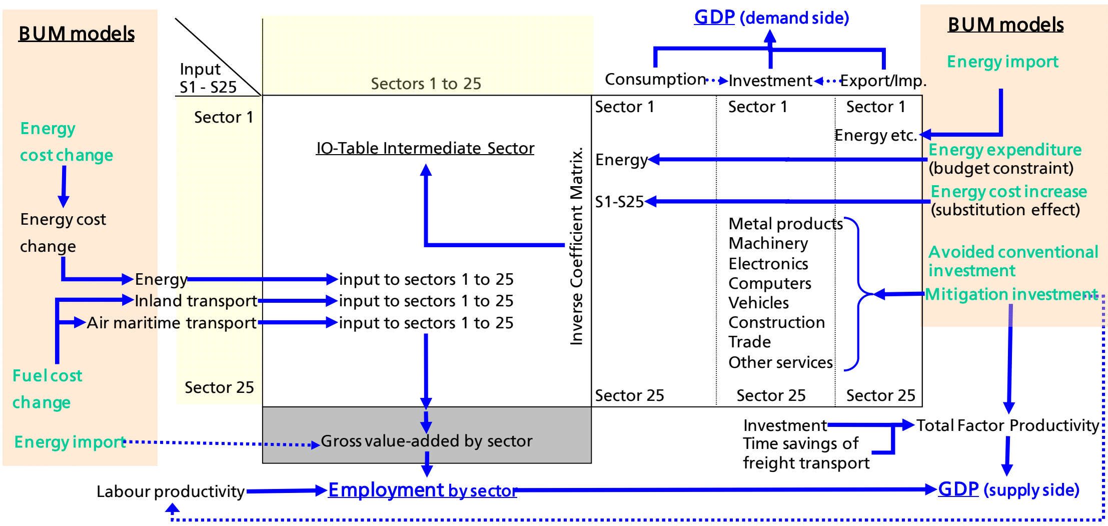


Source: ADAM-M1, Fraunhofer-ISI

Figure 13-2: Conceptual structure of direct effects and second round economic effects of mitigation policy

13.2 Feeding the bottom-up impulses into the ASTRA model

ASTRA already incorporates the micro-macro-bridges from the bottom-up transport system models to the economy. For the ADAM project, the micro-macro-bridges from the bottom-up models describing the energy system in the residential sector, services sector, industry sector, renewables and energy conversion sector to the economy had to be established. This was achieved by coupling ASTRA via the Virtual Model Server (VMS) and its components TRANSFORM and IMPULSE to these bottom-up models. This concept is called the ADAM-HMS (see section 3). The linkages to the bottom-up models (BUM) and their further take-up in the economic models of ASTRA are presented in Figure 13-3.



Source: ADAM-M1, Fraunhofer-ISI

Figure 13-3: Feeding the bottom-up impulses of mitigation policy into the ASTRA model

Broadly speaking, the impacts from the energy and transport system and thus from the mitigation policies can be divided into those on (1) consumer demand, (2) the production of goods and services, (3) the trade balance of the 29 economies, and (4) the impacts on government budget.

Consumer demand is directly affected by the changes of energy expenditures via the *budget effect* and the *substitution effect*. In case of energy efficicency gains less money needs to be spent on energy and thus more money can be spent for other purposes and sectors. This is called the budget effect. The substitution effect occurs as prices of different goods and services change differently as a reaction to the mitigation policies. This depends on the sectoral investment required for mitigation and the efficiency improvements that can be achieved, such that depending on investment and cost changes, CO_2 prices, energy content and elasticities, the sectoral consumer demand will be restructured, e.g. if CO_2 prices increase, CO_2-intensive goods and services will be substituted by less CO_2-intensive ones.

The production of goods and services reacts in two ways: first, the adaptation of the energy and transport system estimated by the bottom-up models lead to additional investments e.g. into efficiency technologies in households, industry and services, into renewables and into buildings. Avoided investments in conventional energy technologies are also considered. Second, changes of energy expenditures affect the exchange of intermediate goods in the input-output-table. Third, the mitigation investment made by a sector changes the cost structrue of the sector and thus feed into the input-output table. The latter two impacts are then felt on the value-added of each sector, employment and finally the GDP from the supply side, while the direct impacts on the consumer side and to some extent also the additional demand for investment goods also affect the GDP on the demand side.

Thirdly, the direct impacts on the trade balance have to be considered. These consist of reductions of energy imports of fossil fuels that have a positive impact on the demand side of GDP, as well as an increase of the value-added of the energy sector as the share of domestic energy production e.g. by renewables is growing.

Fourth, the impacts on the government budget have to be considered as they could be significant for climate policy. This concerns two issues (1) the direct policy impacts estimated by the bottom-up models, and (2) the indirect impacts calculated in ASTRA e.g. the change of revenues of fuel taxes. The direct policy impacts would consist of subsidies (e.g. if the introduction of a new technology requires financial support for selling the first units on the market, or if R&D is (partially) funded by the government) and programme cost (e.g. if a national authority is set-up to monitor energy efficiency improvements or to promote renewables and insulation of houses, or if loans at interest rates that are lower than the market interest rates are provided by the government to finance mitigation investments). Indirect impacts emerge if those variables are affected that form the base for taxation e.g. fossil fuel taxes that are reduced either because the increase of energy efficiency reduced fuel demand and thus the fuel tax revenues or because fuel switch to other fuels occur that are lower taxed e.g. biofuels or CNG. A new element of the revenue base of governments becomes the selling of the CO_2 certificates of the GHG emissions trading system (ETS). Assuming that these certificates are mainly auctioned to the emitting sectors the government will receive significant revenues from the CO_2 certificates. Thus the analysis of the mitigation policy has also to consider the use of these revenues. Options would be to fund the mitigation investment, to reduce the direct taxes, to reduce the government debt or to apply a mix of these options.

One specific on the interface with the bottom-up models needs to be explained. Though often the analysis of mitigation policies refers to the (energy) cost changes – mostly expected to be cost increases – this does not constitute the relevant variable to be considered in macro-economic models. *The relevant variable is the expenditures for energy use* and not the cost change, which only indicates a cost per unit of energy (e.g. per kWh). The cost only then presents the relevant variable if energy demand does not change. However, the nature of many climate mitigation policies is actually that they save energy and thus decrease energy demand. This makes that the relevant input to consider from the bottom-up models is not the cost change but the change of energy expenditures, which is the multiplication of unit cost of energy by the energy demand. This is expressed in the following equation showing also that in most cases it is not the absolute change of energy expenditures that is provided by the bottom-up models, but the change compared with the reference scenario:

$$EE_{EC,EP} = P_{EC,EP} * Q_{EC,EP} \qquad \text{(eq. 13-1:)}$$

$$\Delta EE_{EC,EP} = \Delta P_{EC,EP} * \Delta Q_{EC,EP} \quad \text{expressed as change to reference scenario} \qquad \text{(eq. 13-2:)}$$

Where: EE = energy expenditure [€].

P = cost per unit of energy [€/kWh, €/l, €/kg, etc.].

Q = consumption of energy [kWh, l, kg, etc.].

ΔEE = change of energy expenditure to reference scenario [€ or %].

ΔP = change of cost per unit of energy to reference scenario [€/unit or %].

ΔQ = change of consumption of energy to reference scenario [kWh, l, kg or %].

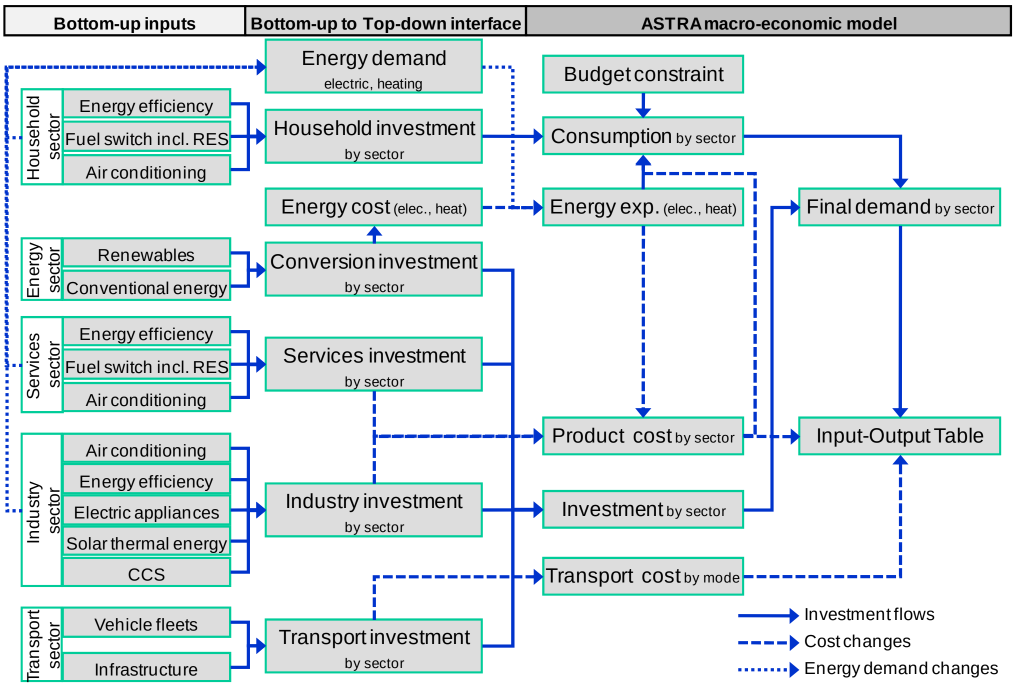
EC = index for the EU27+2 countries.

EP = index for the energy use purposes (heating, electricity, fuel).

Figure 13-4 presents an overview on the linkage of the bottom-up impulses of the mitigation investment and energy expenditures to the ASTRA model. The figure concentrates on these two bottom-up impulses as they seem more relevant for the economic impacts and the structural change induced by the mitigation policy. The figure starts from the left hand side with the input from the bottom-up models divided into five sectors: households, services, industry, transport and conversion (i.e. energy sector). In each sector different kind of mitigation measures are implemented, which are grouped into a few sector-specific categories. In particular, the categories relevant for requiring investment are shown, e.g. in the household sector it is the increase of energy efficiency by investing in insulation of buildings, new heating systems or efficient electric appliances, the fuel switch by investing in renewables (e.g. solar heating of water, geothermal heating) or natural gas and the effects of air conditioning, which have been more important for the Reference Scenario than the 2-degree scenarios. In fact, investment in air conditioning is lower in the 2-Degree scenarios than in the Reference Scenario.

Moving from the left-hand side to the middle of the figure i.e. the interface between bottom-up and macro-economic model the bottom-up impulses are converted. The investment are split onto the 25 economic sectors of the ASTRA model considering individual technological splits for each measure/technology.

Consistent with the mitigation investment the bottom-up models either provide the change of energy demand (e.g. achieved by energy efficiency investment), the change of energy cost or the change of energy expenditure to the interface with the economic model. This input is aggregated across all mitigation measures by each bottom-up model. The only differentiation made is that energy usages are differentiated into electricity, heating and transport fuels. However, the final impacts on transport energy demand are determined in the transport sector bottom-up model. Thus each model delivers at the end a sectoral change of energy expenditures, which can feed into the consumption and investment models of ASTRA, though the way the energy expenditures are treated differs for the sectors. The household sector affects the consumption expenditures and the consumption split. The conversion sector affects both: consumption and business sectors (i.e. the input-output table structures) as in both choices of actors depend on energy expenditures. The services and industry sector first experience changes of their product cost via (1) their own mitigation investment, and (2) their changes of energy expenditures, and only from the changed product cost the impacts go into the consumption and the business sector. The transport sector is integrated more directly into consumption and business sector as it is part of the ASTRA model itself.



Source: ADAM-M1, Fraunhofer-ISI

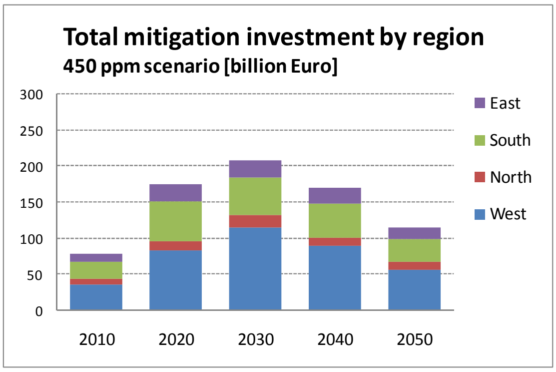
Figure 13-4: Linking and translating the bottom-up impulses of mitigation investment and energy expenditures into the ASTRA model

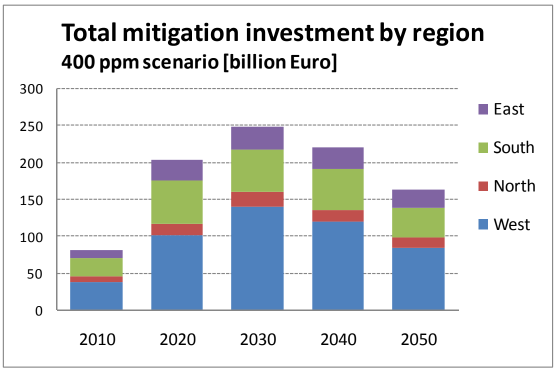
13.3 Macro-economic cost and investment impulses of mitigation in Europe

The list of bottom-up impulses that have been calculated by the bottom-up models and delivered to the macro-economic model ASTRA includes the following eight factors.

- Mitigation investments,
- energy demand change,
- energy cost changes,
- energy expenditure change resulting from combined demand and cost changes,
- change of fossil energy imports,
- subsidies to support R&D, new technologies or new organisational measures,
- programme cost of mitigation policies, and
- revenues from CO_2 certificates.

The bottom-up impulses can be analysed across European regions (West, North, South, East as in previous sections), differentiated for the sectors requiring the mitigation investments. Figure 13-5 presents the total mitigation investment in the European regions. Around 2030 both scenario reach the peak of mitigation investment, with about 200 billion € in 450 ppm scenario and 250 billion € in 400 ppm scenario. The pattern slightly differs between the scenarios. The 400 ppm scenario requires a more ambitious growth path of investment as well as a higher level of investment after 2030 compared with the 450 ppm scenario.

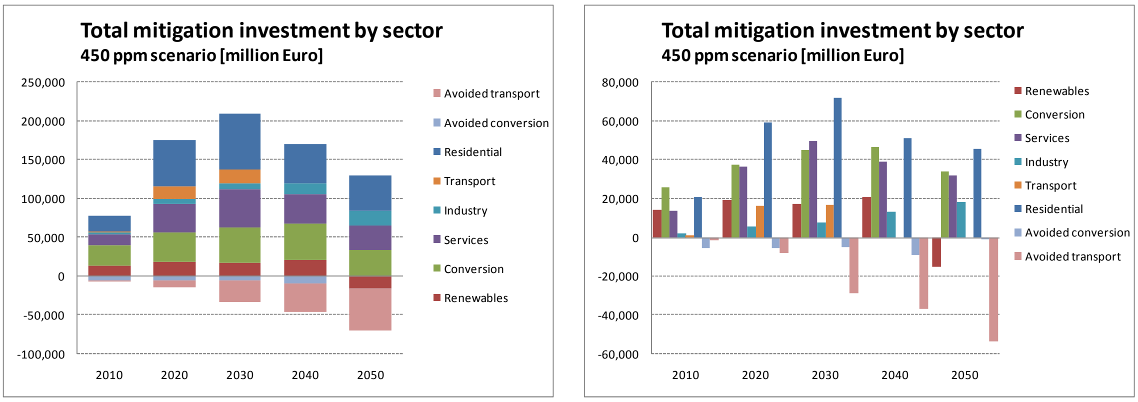




Source: ASTRA and bottom-up models, ADAM-M1

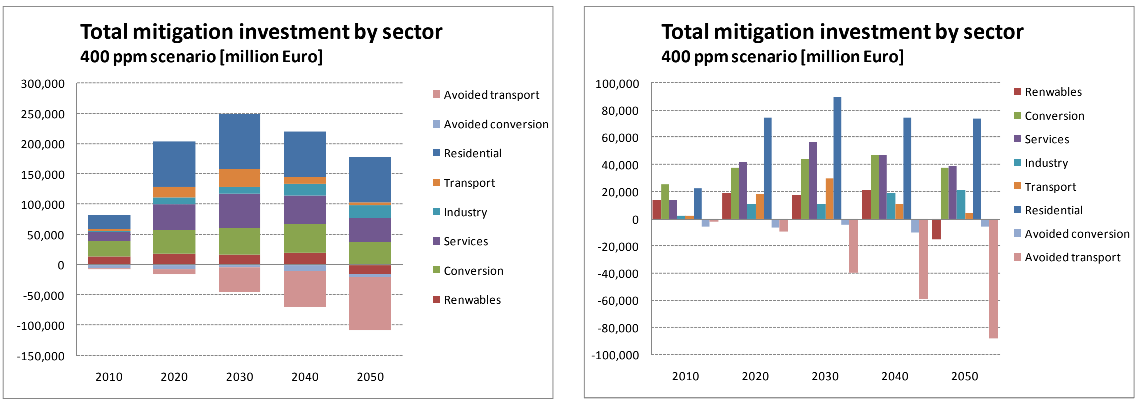
Figure 13-5: Mitigation investment in 450 ppm and 400 ppm scenario in EU regions

The major sectors that have to undertake the mitigation investment can be differentiated into renewable energies, conversion sector. services, industry, transport and residential, following the structure of the bottom-up models in the ADAM-HMS. The sectoral mitigation investment plus avoided investment into conventional technologies are shown in Figure 13-6 and Figure 13-7 for the 450 ppm scenario and the 400 ppm scenario, respectively. The largest investments have to be made in the residential sector followed by the services and conversion sector (see also Table 13-1). Looking at the renewable investment and the other investment in the conversion sector, it shows that in the first two decades the focus will be on these two sectors, though around 2020 the residential sector is catching-up i.e. the timing of the investment plays a role as through learning-by-doing on renewables in the conversion sector also stimulus is generated for the other sectors in their direct usage of renewables. Two sectors, conversion and transport, also report about avoided investment as in the conversion sector some conventional power plants will not be built and in transport the changes of demand, in particular of freight transport, require fewer road vehicles saving investment.



Source: ASTRA and bottom-up models, ADAM-M1

Figure 13-6: Mitigation investment in 450 ppm scenario in EU27+2



Source ASTRA and bottom-up models, ADAM-M1

Figure 13-7: Mitigation investment in 400 ppm scenario in EU27+2

Table 13-1 improves the understanding of the total mitigation efforts required from the different sectors. The order of magnitude of the sectors in both scenarios is similar: residential requires more than one third of all investment cumulated over the period 2009 until 2050. Conversion and services need about one fifth in the scenario with lower share in the 400 ppm scenario. Renewables, industry and transport account for less than 10 % each, with a higher share in the 400 ppm scenario for industry and transport. For the transport sector the numbers should be at the lower end as it was not possible to separate completely all the mitigation investment from the total investment in the sector. In total the cumulated mitigation investment required for the EU27+2 amounts to € 6.6 billion in the 450 ppm scenario, and 8 billion € in the 400 ppm scenario. On the other hand, due to mitigation significant investment are not needed as they would have been in the Reference Scenaro, which are called *avoided investment*. The avoided investment in both scenarios amount to about one fifth of the investment required for mitigation, such that the balance of investments caused by the mitigation policy amounts to € 5.4 billion and € 6.3 billion in the 450 ppm and 400 ppm scenarios, respectively.

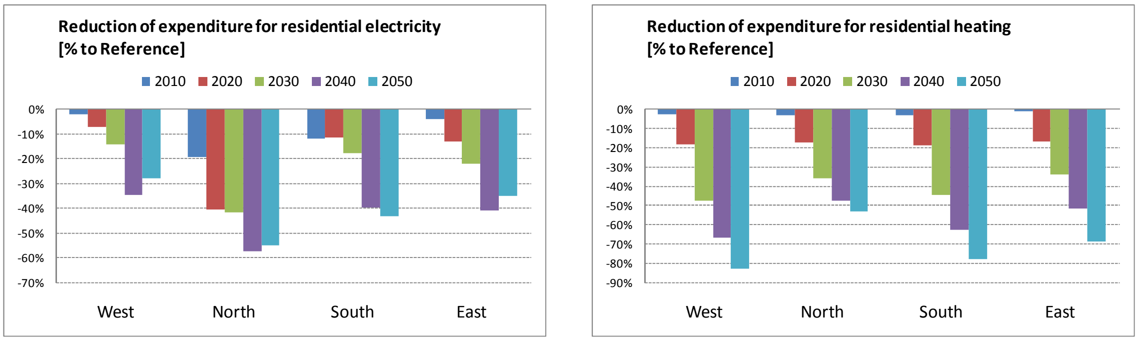
Table 13-1: Cumulated mitigation investment in the different sectors in EU27+2

[million Euro]	450 ppm scenario				400 ppm scenario			
Cumulation 2009 until:	2020	2030	2040	2050	2020	2030	2040	2050
Renewables	191,423	328,173	528,635	**606,075**	191,423	328,173	528,635	**606,075**
Conversion	365,529	751,687	1,197,004	**1,553,734**	368,014	763,125	1,212,359	**1,586,463**
Services	312,571	735,791	1,124,634	**1,474,184**	341,772	831,606	1,293,054	**1,716,732**
Industry	48,378	117,911	225,870	**387,215**	121,419	231,521	383,403	**587,391**
Transport	22,200	187,533	317,400	**324,067**	33,455	227,743	476,060	**574,927**
Residential	436,473	1,147,512	1,755,828	**2,283,693**	542,568	1,437,301	2,255,054	**3,015,122**
Total mitigation	**1,376,573**	**3,268,607**	**5,149,371**	**6,628,968**	**1,598,650**	**3,819,468**	**6,148,565**	**8,086,709**
Avoided conversion	-68,233	-79,379	-154,275	**-178,201**	-70,719	-90,817	-169,631	**-210,930**
Avoided transport	-51,534	-205,586	-527,621	**-1,033,204**	-60,447	-268,969	-747,646	**-1,598,772**
Total avoided	-119,767	-284,965	-681,896	**-1,211,405**	-131,166	-359,785	-917,276	**-1,809,701**
Net mitigation	**1,256,806**	**2,983,643**	**4,467,475**	**5,417,563**	**1,467,484**	**3,459,683**	**5,231,289**	**6,277,008**

Source: ASTRA and bottom-up models, ADAM-M1

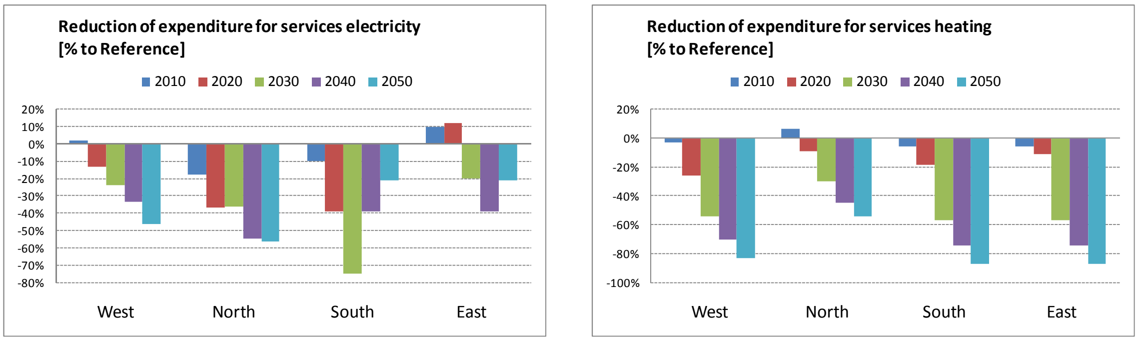
The mitigation investments increase the product cost of goods and services. This effect differs between the service sectors and the industry sectors. Services have to spend three- to four times the mitigation investment compared to industry in the above table, although value-added in the tow sectors is comparable. Consequently the cost of services increases more than for goods. Broadly the bandwidth of cost increases of services is between +2 % and +10 %, while for goods from the industry sectors the cost increase is rather between zero and +2 %.

Figure 13-8 and Figure 13-9 present an example of how energy expenditure develops in the four regions, using one representative country per region (Germany for West, Sweden for North, Italy for South and Poland for East), since an aggregation or averaging of the changes of expenditure is less meaningful. It is obvious that the energy saving measures become very successful such that the unit cost increase of energy is overcompensated by the savings in energy demand. For electricity the savings reach levels of -30 % to -60 % of expenditures in the residential and services sector. For heating the savings could even become larger with savings in 2050 being between -40 % and -80 % of expenditures for heating.



Source: ASTRA and bottom-up models, ADAM-M1

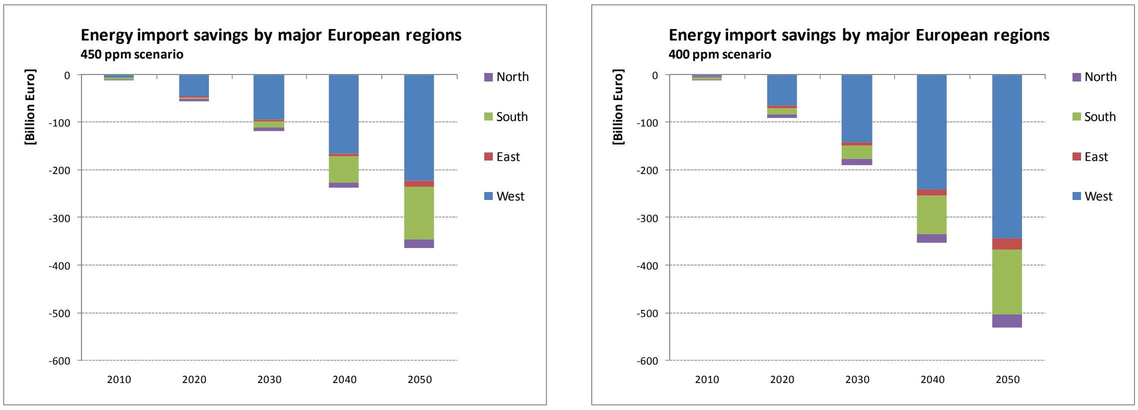
Figure 13-8: Change of residential energy expenditure in 400 ppm scenario in EU regions



Source: ASTRA and bottom-up models, ADAM-M

Figure 13-9: Change of services energy expenditure in 400 ppm scenario in EU regions

The energy savings achieved by the mitigaton policy significantly reduce the imports of fossil energies into the EU. Figure 13-10 presents the import savings in monetary terms for the 450 ppm and 400 ppm scenarios. In the former scenario the annual savings amount to about € 360 billion in 2050 and in the latter to € 520 billion.



Source: ASTRA and bottom-up models, ADAM-M1

Figure 13-10: Savings of energy imports in 450 ppm and 400 ppm scenarios in EU27

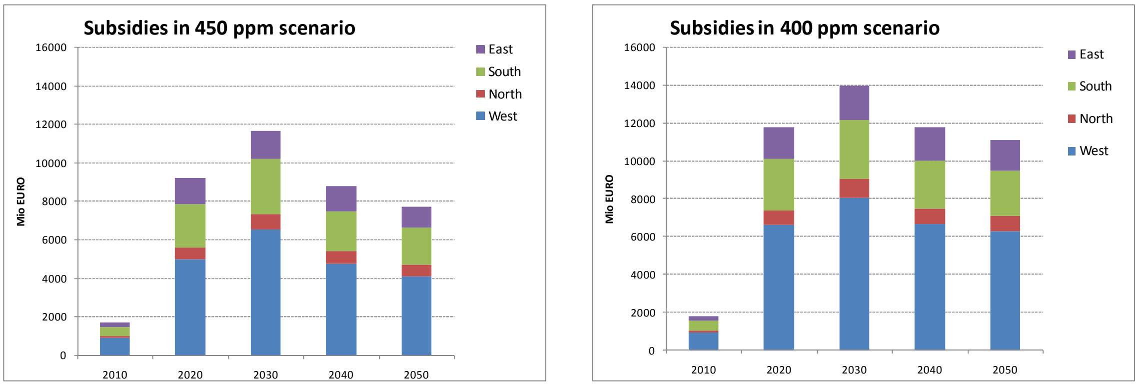
The interesting thing to note is that by 2050 the accumulated savings of energy imports come very close to the required mitigation investment, though this is not the case for earlier years. Table 13-2 reveals that up to 2040 the mitigation investment are significantly higher than the energy import savings (between € half a billion and close to € 2 billion). However, at this point of time the annual savings are more than € 200 billion and € 300 billion in energy import savings (see Figure 13-10), which is above the annual mitigation investment such that the balance of the cumulated numbers strongly shifts towards the energy import savings such that within a decade cumulated savings become larger than the additional mitigation investment.

Table 13-2: Comparison of cumulated mitigation investment and savings of energy imports for EU27+2

[billion Euro]	450 ppm scenario				400 ppm scenario			
Cumulation 2009 until:	2020	2030	2040	2050	2020	2030	2040	2050
Mitigation investment	1,257	2,984	4,467	5,418	1,467	3,460	5,231	6,277
Energy import saving	-340	-1,174	-3,009	-6,052	-507	-1,890	-4,695	-9,170
Saldo (Invest-Saving)	**917**	**1,810**	**1,459**	**-634**	**961**	**1,570**	**537**	**-2,893**

Source: ASTRA and bottom-up models, ADAM-M1

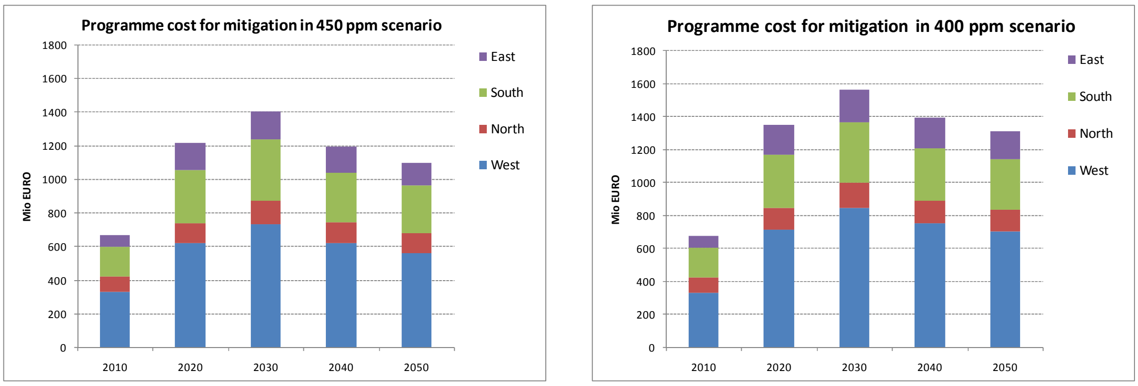
The implementation of the mitigation policies requires government subsidies in some cases (e.g. the market penetration of new technologies like electric vehicles or CCS). These subsidies have been also considered by the bottom-up models and provided to the macro-economic in which they affect the government budget. Figure 13-12 presents the subsidies for the 450 ppm and 400 ppm scenarios. Their peak amounts to about € 12 billion and € 14 billion annually in 2030. This means also that governments need to provide directly a significant amount of money to stimulate the mitigation investment.



Source: ASTRA and bottom-up models, ADAM-M1

Figure 13-11: Subsidies for mitigation measures in 450 ppm and 400 ppm scenarios in EU regions

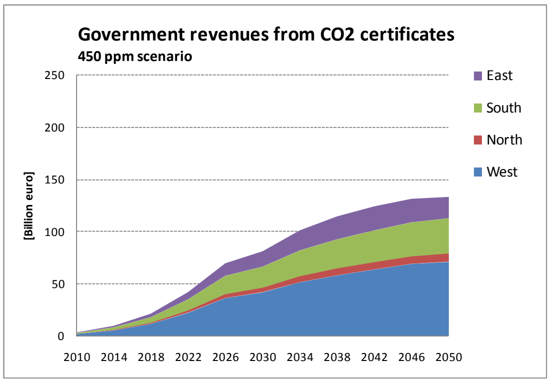
Besides subsidies, governments will also need to provide administrative support to implement their mitigation policy. This could be to set-up authorities that control and promote national initiatives to foster energy efficiency or to provide loans with lower-than-market interest rates. Figure 13-12 presents these programme cost for the 450 ppm and 400 ppm scenarios, which are one order of magnitude lower than the subsidies. However, after 2020 the programme cost also amounts to more than € 1 billion annually in both scenarios.

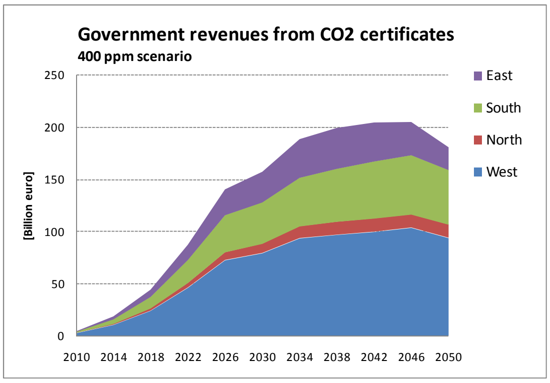


Source: ASTRA and bottom-up models, ADAM-M1

Figure 13-12: Programme cost for mitigation measures in 450 ppm and 400 ppm scenarios in EU regions

A further element of the scenarios is the revenues generated from auctioning of the CO_2 certificates. In ASTRA it is assumed that after 2012 100 % of the CO_2 certificates are auctioned such that they generate revenues to the government. The government then leaves 30 % of these revenues in the government, e.g. to finance the subsidies of the mitigation investment and the programme cost, but also to compensate for the loss of fuel tax revenues due to the energy savings achieved by mitigation. 20 % of the revenues are "burned" as the CO_2 certificates increase the price of goods and services (in particular of energy) and stimulates inflation. Figure 13-13 presents the total revenues from auctioning the CO_2 certificates. They are influenced by (1) the certificate prices, and (2) the CO_2 emissions. The lower level of certificate prices in the 450 ppm scenarios leads to the fact that the revenues reach a maximum of about € 130 billion annually, while in the 400 ppm scenario the maximum reaches about € 200 billion. However, the certificate prices is more than twofold as high in the 400 ppm scenario, which shows that the reductions of CO_2 emissions limit the potentials of revenue generation from CO_2 certificates. Actually, in the 400 ppm scenario the peak of revenues generated by the certificates is around 2045. After that the revenues reduce as the CO_2 emissions decrease strongly.





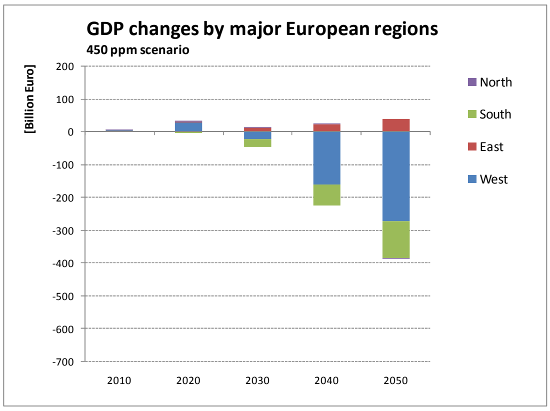
Source: ASTRA model, ADAM-M1

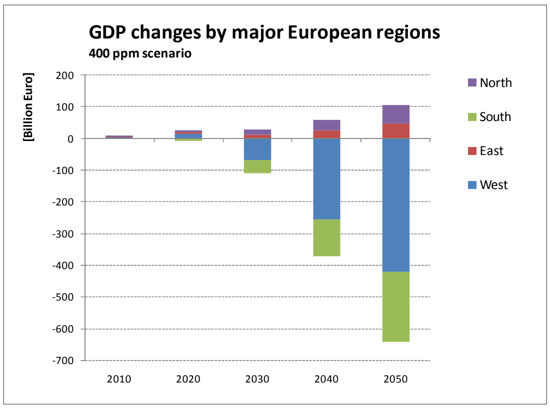
Figure 13-13: Government revenues from auctioning of CO_2 certificates in 450 ppm and 400 ppm scenarios in EU regions

13.4 Macro-economic impacts of 2-degree scenarios in Europe

In the previous section the bottom-up impulses estimated by the bottom-up models and feeding into the macro-economic models of ASTRA were explained. This section continues with the presentation of the macro-economic impacts for Europe caused by the mitigation policy as it was implemented in the bottom-up models.

At first we have a look at the impact on GDP. Figure 13-14 presents the changes of GDP in the 2-degree scenarios, 450 ppm scenario and 400 ppm scenario, compared with the Reference Scenario [for details see Jochem et al. 2009]. It can be noted that in the first decade until 2020 GDP is slightly increasing, driven by the mitigation investment. Over time further second round effects develop (e.g. cost changes of goods and services, changes of government revenues, structural change) that lead to reductions in GDP for the whole EU27+2. However, the impacts differ for the European regions. The Eastern and Northern countries benefit from the mitigation policy, which occurs partially as the relative impulse of the investment (i.e. the ratio of mitiagtion investment to GDP) is larger in these regions, at least compared to the Western region, and as some specific sectors benefit overproportionally, such asike agriculture in the Eastern countries. Further, it can be observed that the impact in the 400 ppm scenario is larger than in 450 ppm scenario.





Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-14: Impact on GDP in the 450 ppm and 400 ppm scenarios in EU regions

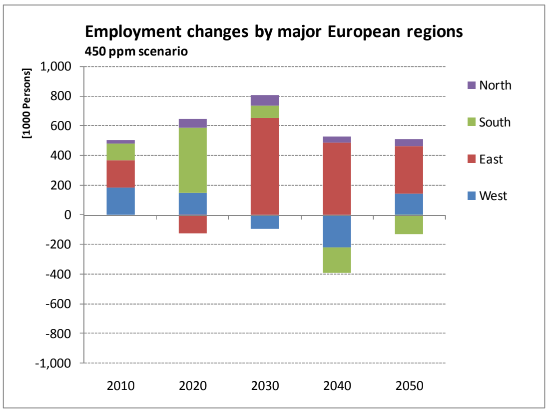
Table 13-2 presents the impact on GDP as percentage change to the reference scenario as well as percentage change between 400 ppm and 450 ppm scenarios. This reveals that in relative terms the Southern region is affected most by the mitigation policy followed by the Western region. Northern and Eastern countries benefit in both scenarios from the mitigation, as explained above.

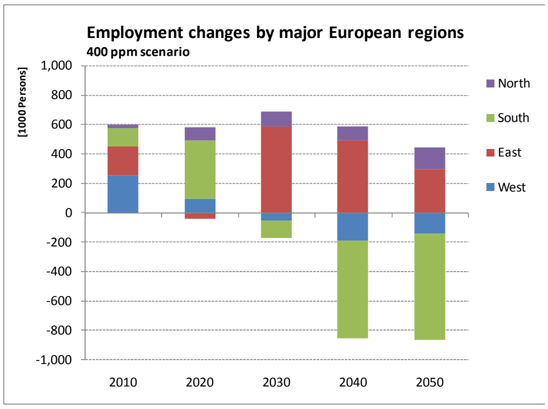
Table 13-3: Impact of 2-Degree scenarios on GDP [%-change to scenario]

	450 ppm to Reference					**400 ppm to Reference**					**400 ppm to 450 ppm**				
	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
West	0.1%	0.3%	-0.2%	-1.5%	-2.2%	0.1%	0.2%	-0.7%	-2.4%	-3.5%	0.0%	-0.1%	-0.5%	-0.9%	-1.2%
East	0.1%	0.7%	1.3%	2.0%	3.1%	0.1%	0.8%	1.5%	2.5%	4.0%	0.1%	0.1%	0.2%	0.5%	0.8%
South	0.0%	-0.2%	-0.7%	-1.8%	-2.8%	0.0%	-0.3%	-1.3%	-3.2%	-5.5%	0.0%	-0.1%	-0.6%	-1.5%	-2.8%
North	0.0%	0.1%	0.2%	0.2%	0.0%	0.0%	0.3%	1.2%	2.1%	3.1%	0.0%	0.2%	1.0%	1.9%	3.1%
EU27	0.1%	0.2%	-0.3%	-1.2%	-1.7%	0.1%	0.1%	-0.6%	-1.8%	-2.7%	0.0%	-0.1%	-0.3%	-0.6%	-1.0%

Source: ASTRA calculations, Fraunhofer-ISI

The impact on employment is more moderate than on GDP. Figure 13-1 shows that in the 450 ppm scenario the EU as whole is able to increase its employment with a maximum increase in 2030 of about +700,000 more persons employed, while in the 400 ppm scenario employment increases only for the first two decades and is reduced afterwards. The changes of GDP are reflected in losses of employment in the South and gains in the East and North, while in the West structural change seems to occur as the lower GDP is only translated into rather moderate employment reductions.





Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-15: Impact on employment in the 450 ppm and 400 ppm scenarios in EU27

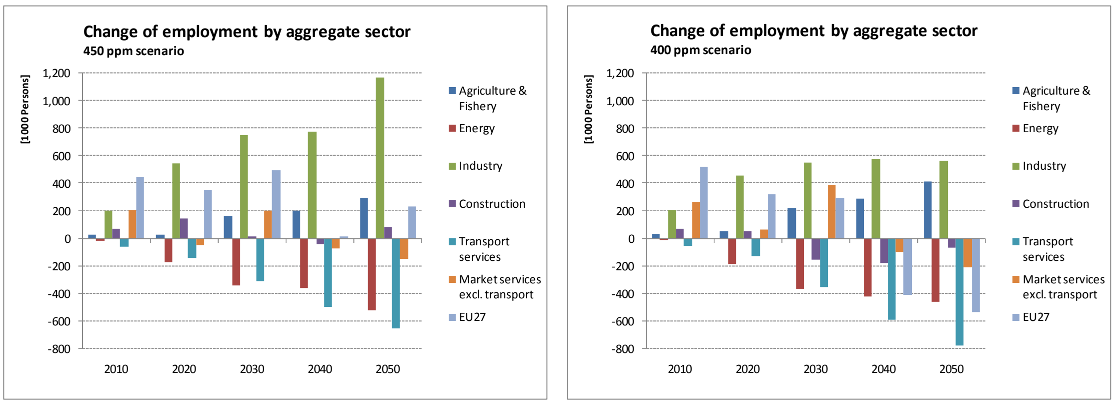
Table 13-3 presents the percentage changes of employment in the different regions and the EU27+2. In the 450 ppm scenario employment is increased by a moderate +0.2 % over most of the period until 2050, though on regional level there are some larger changes including also periods in which employment is slightly reduced.

Table 13-4: Impact of 2-Degree scenarios on employment [%-change to scenario]

	450 ppm to Reference					400 ppm to Reference					400 ppm to 450 ppm				
	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
West	0.2%	0.1%	-0.1%	-0.2%	0.2%	0.2%	0.1%	0.0%	-0.2%	-0.2%	0.1%	0.0%	0.0%	0.0%	-0.3%
East	0.5%	-0.3%	1.7%	1.5%	1.1%	0.5%	-0.1%	1.5%	1.5%	1.0%	0.0%	0.2%	-0.2%	0.0%	-0.1%
South	0.2%	0.7%	0.1%	-0.3%	-0.3%	0.2%	0.6%	-0.2%	-1.2%	-1.4%	0.0%	-0.1%	-0.3%	-0.9%	-1.2%
North	0.2%	0.5%	0.6%	0.4%	0.4%	0.2%	0.7%	0.8%	0.8%	1.4%	0.0%	0.2%	0.2%	0.4%	1.0%
EU27	0.2%	0.2%	0.3%	0.0%	0.2%	0.3%	0.2%	0.2%	-0.2%	-0.3%	0.0%	0.0%	-0.1%	-0.2%	-0.5%

Source: ASTRA calculations, Fraunhofer-ISI

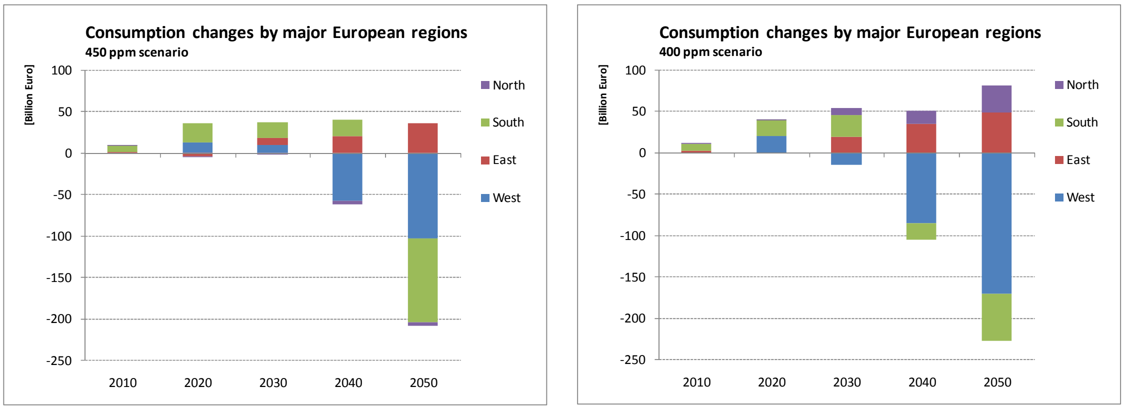
Looking at Figure 13-16 provides some background on the employment impacts. In general, the industry and the agriculture sector experience increasing employment, while energy and service sectors loose employment. The agriculture sector benefits from the increased demand for biomass for energy purposes and the industry sector from the demand for mitigation investments of all kinds (e.g. renewable technologies, efficient vehicles, efficient electric appliances). Furthermore, the industry sector has lower mitigation investment than the services sector such that the prices of manufactured goods hardly increase. For market services, the opposite applies: their mitigation investments are higher than for industry (see Table 13-1) such that the prices of their services increase stronger reducing the demand from services, which is reinforced as some services are highly price sensitive as they do not constitute a basic need e.g. restaurants or wellness activities and thus can be avoided/substituted more easily. Employment in the energy sector is significantly reduced due to the reduction of energy expenditures caused by the energy savings. Here ASTRA operates with nearly fixed labor productivity of the energy sector between the scenarios, though the structural change in the energy sector (e.g. more decentralised renewables and less large-scale power-plants) would suggest the need to apply a more adaptive labor productivity compensating for part of the loss of expenditures and refelecting the structural change in the energy sector. Transport services also reduce employment as the transport demand, in particular of labor-intensive road freight, is reduced.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-16: Impact on sectoral employment in the 450 ppm and 400 ppm scenarios in EU27

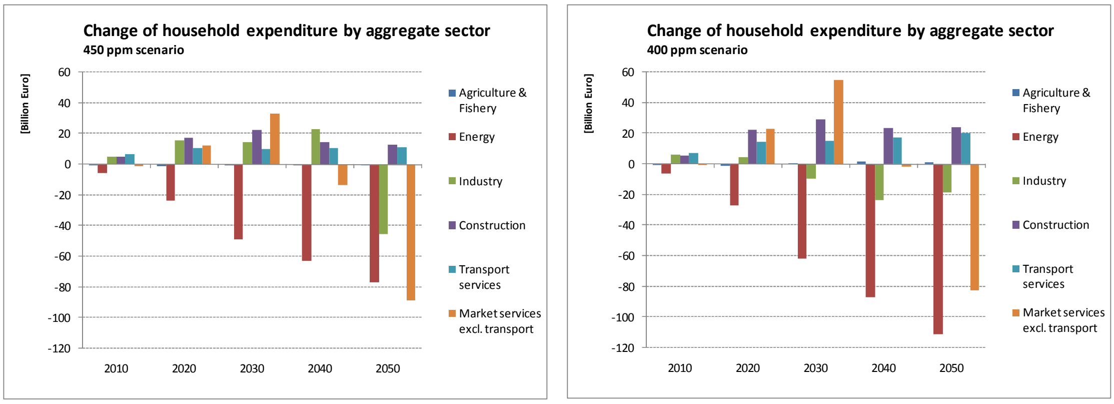
Figure 13-17 presents the change of consumption (i.e. the expenditure of households including investment) in the European regions. Consumption constitues the variable in ASTRA which follows GDP developments most closely and thus is also subject to the second round effects that enfold over time. Thus we oberve in both scenarios an increased consumption in the first two decades, followed by two decades with reduced consumption. For Eastern and Norhern countries the development is even more positive with consumption growing until 2050, in particular in the 400 ppm scenario.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-17: Impact on consumption in the 450 ppm and 400 ppm scenarios in EU27

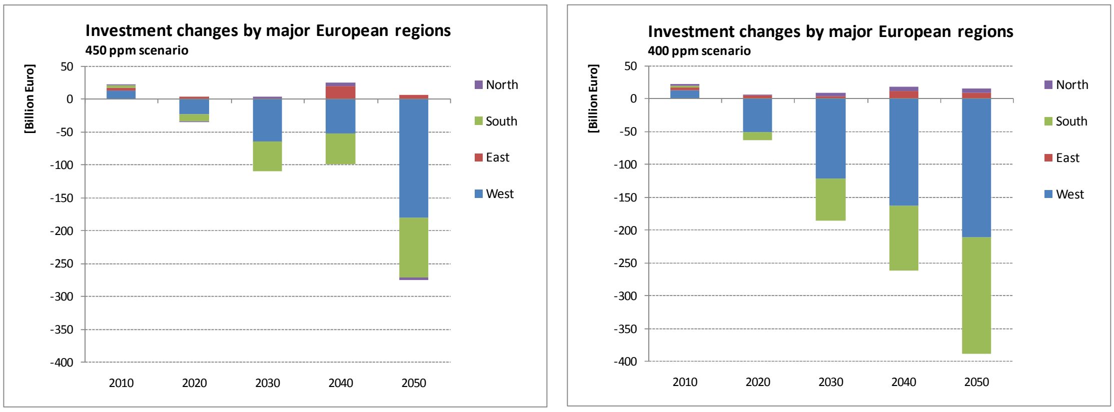
Looking at the sectoral structure of consumption in Figure 13-18 one broadly observes a similar pattern to employment, but not exactly the same. Expenditures for energy show the largest reductions, coming from the efficiency improvements. In the first two decades when GDP remains stable the losses of energy demand lead to gains in other sectors controlled by the budget constraint (in this case the opposite to a constraint as the savings of energy expenditures frees money that is now spent for other purposes). In the last two decades this does not hold any more, due to the second round effects i.e. the loss of GDP and disposable income such that the overall leveölof consumption is reduced, which affects three sectors - energy, industry and other market services - for different reasons. On the other hand two sectors benefit, construction due to the massive mitigation investment in the residential sector in particular for insulation of buildings, and transport services, which become more attractive due to their strong savings of energy as well as due to a fiscal effect specific to transport. This is that fossil fuels in transport are highly taxed, but the mitigation policies lead to substitution of fossil fuels by alternatives (e.g. electricity, biofuels, CNG). These are all taxed at lower rates but net of taxes they may be more expensive than the fossil counterparts. Since consumption in ASTRA is presented net of taxes, such a shift between fuels would reduce the tax payments and increase consumption spending for transport, though in the pockets of the people the change could be negligible.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-18: Impact on sectoral consumption/household expenditure in the 450 ppm and 400 ppm scenarios in EU27

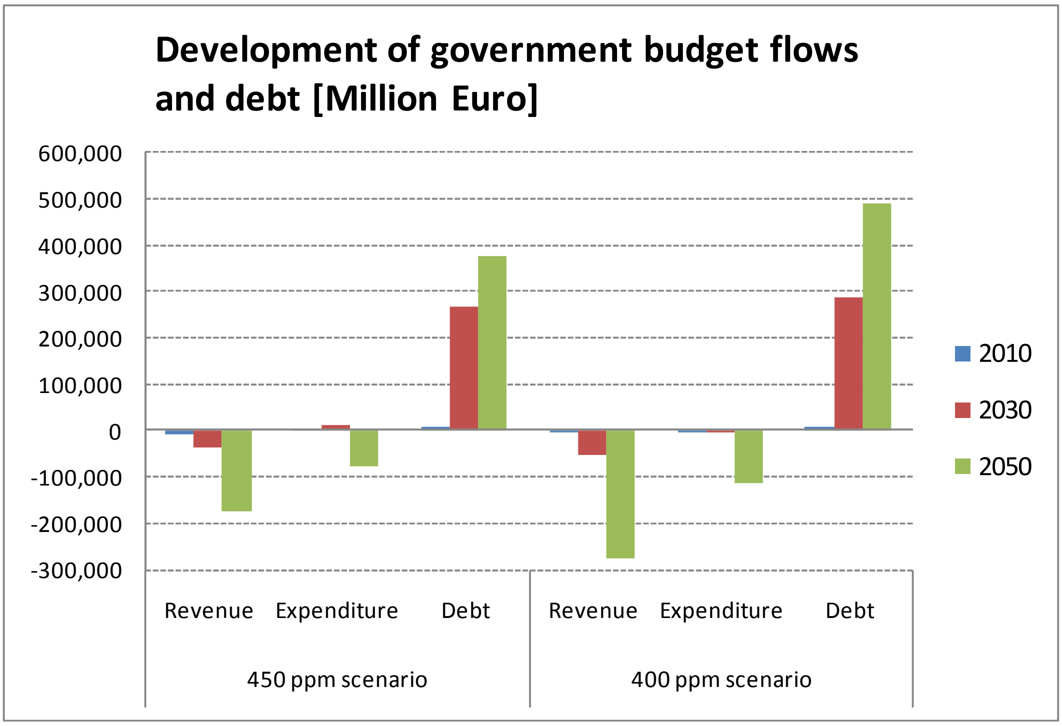
Figure 13-19 presents the changes of total investment in the European regions. In the first decade total investments are reduced in the Western and Southern countries, while they remain stable or slightly increase in the Eastern and Northern countries. This is part of the explanation for why GDP in these countries develops more positively than in the other countries. The most relevant question is, why despite the huge additional mitigation investment does the total investment decrease? There seem to be two major reasons for that, which will be further analysed in the following: (1) ASTRA includes an endogenous investment model, which also estimates the investment of the 25 economic sectors considered in the economic models and the structure of the mitigation policies affects these investments negatively. We would argue that this reduction makes our assessment of mitigation a pessimistic approach and we will explain this later. (2) The reductions of fuel taxes due to energy savings decreases government revenues and increases its debt, which causes crowding out and thus reduces private investment. This could also be tackled by government intervention, which is not considered in the definition of the mitigation policies underlying the assessment of the 2-degree scenarios.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-19: Impact on investment in the 450 ppm and 400 ppm scenarios in EU27

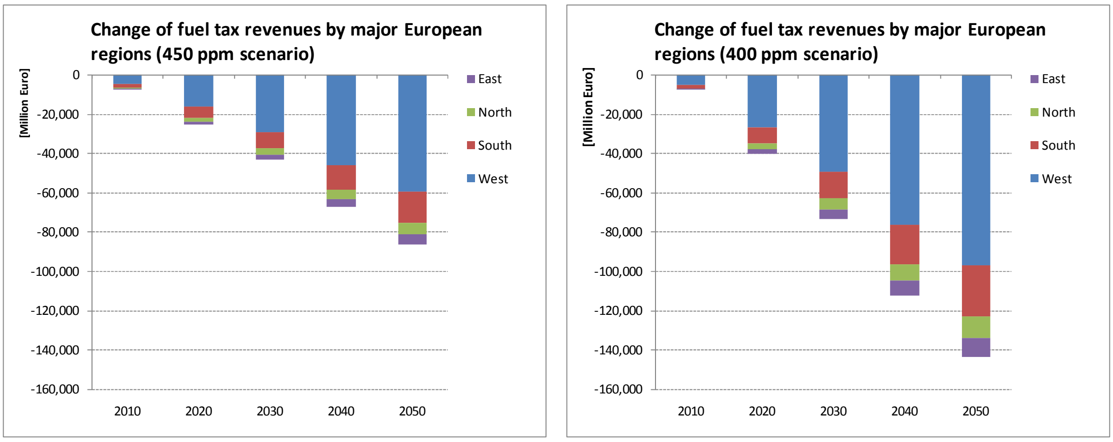
Figure 13-20 provides a closer look at the government debt and the revenue and expenditure side of the government budget. We can observe that in 2030 government revenues have declined, while the expenditures remained roughly stable such that a deficit occured. This is already accumulated over some years such that the government debt increases by close to € 300 billion in 2030. The decline of revenues continues further and though expenditures also reduce – but less than the revenues – the annual budget deficit increases as does the total government debt. The latter is relevant for determining the crowding out effect.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-20: Development of and impact on government budget in the 450 ppm and 400 ppm scenarios in EU27

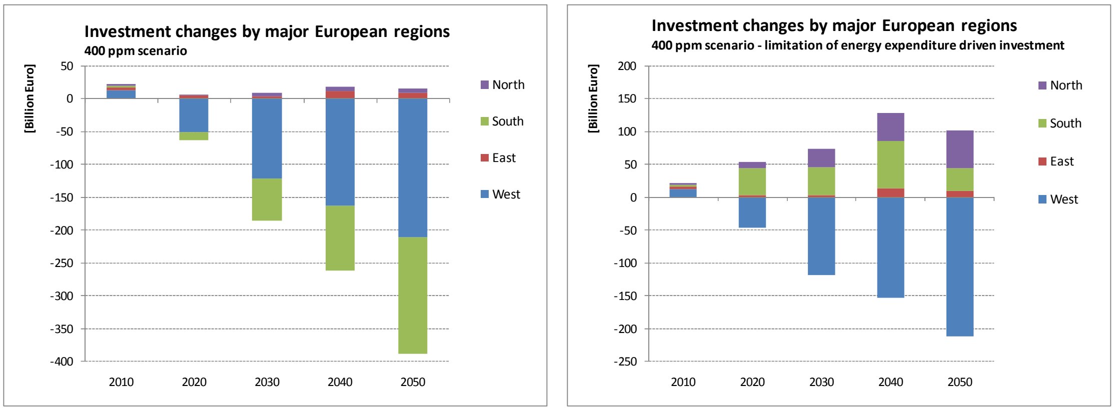
Figure 13-21 presents the revenues from fuel taxes in the 2-degree scenarios. The success of the efficiency measures and the energy savings in the transport sector can be directly observed. Until 2050 fuel tax revenues decrease by more than -€ 80 billion annually in the 450 ppm scenario and by more than -€ 140 billion in the 400 ppm scenario. This is one major reason whygovernment debt increases and dampens private investment.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-21: Impact on fuel taxes in the 450 ppm and 400 ppm scenarios in EU27+2

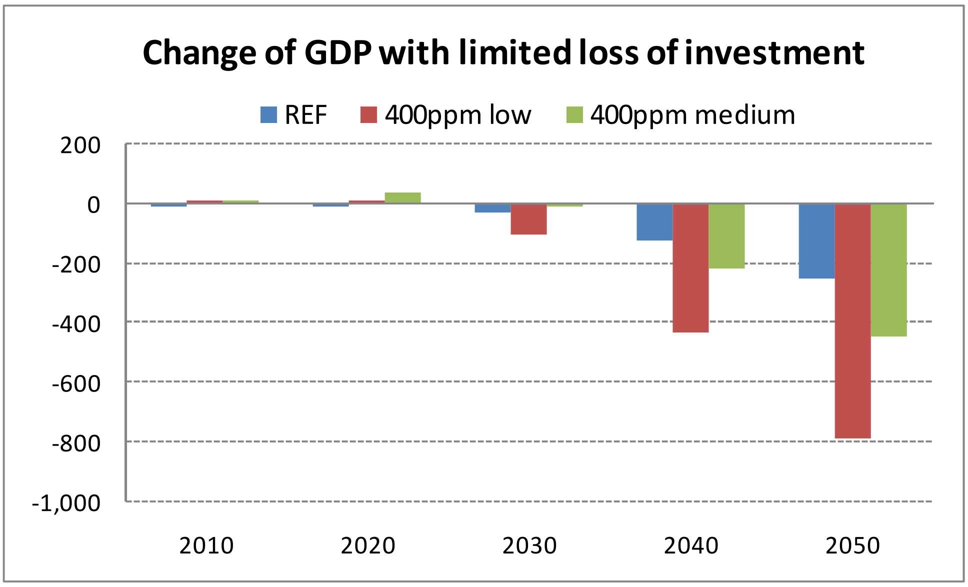
It has been explained that the endogenous ASTRA investment model also dampened the total investment in the mitigation scenarios. Without linking investments to inputs from bottom-up models it turns out that the expenditures for energy i.e. the consumption from the energy sector is one of the important drivers of investments in ASTRA, which is an outcome of the calibration to the period 1990 until 2004. However, the bottom-up models have some overlap with the ASTRA investment model. In particular the energy sector investments should be largely covered by the inputs from the renewables model (PowerACE) and the conversion model (EuroMM). Thus a sensitivity anlysis was made by largely switching-off the endogenous influence of the energy sector on investment demand for the 400 ppm scenario. Figure 13-22 shows the result. The left hand side constitutes the investment figure as presented above for the 400 ppm scenario, but the right hand side shows the switch-off case of the endogenous energy sector investment. In this case, the total investment would be positive in the Western countries and the balance for the EU27 would only be slightly negative in 2050.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-22: Anaylsing the impact of energy expenditure driven investment changes in the 400 ppm scenarios in EU27+2

Figure 13-23 presents the effect on GDP of this improved investment calculation. The figure shows three scenarios against the base case. This includes the Reference Scenario, which differs from the base case by that it incorporates adaptation of the energy sector, the standard 400 ppm scenario as described throughout this report and marked as 400 ppm low since it should be at the lower end of possible scenarios and the 400 ppm medium scenario excluding the endogenous reduction of investment caused by the reduced demand from the energy sector. We can observe that loss of GDP in the Reference Scenario until 2050 is smaller than in the 400 ppm scenario, which is the -2.7 % difference from Table 13-3. On the other hand we can observe that the new 400 ppm medium scenario comes much closer to the Reference Scenario. Considering that most of the adaptation impacts and cost will occur after 2050, while in the mitigation scenarios these impacts largely happen between now and 2050 as well as that positive effects of mitigation e.g. the reduction of fossil fuel imports (as explained in section 13.3) also strengthen after 2050 our analysis confirms that investment into mitigation seems to be the more promising option. This conclusion is obtained through a purely economic analysis. Considering further the possible external cost of adaptation (e.g. health costs, psychological costs of having to move houses because of flooding) the conclusion to invest into mitigation as the better option would be reinforced.



Source: ASTRA calculations, Fraunhofer-ISI

Figure 13-23: Change of GDP with limited influence of energy expenditures of households on investment in 400 ppm scenarios in EU27+2

13.5 Conclusions of the macro-economic assessment

The basic conclusion that can be drawn is that mitigation to meet the 2-degree target of the EU wil not destroying economic development. Some European regions will even be better off with mitigation than without mitigation. A loss of GDP in EU27 of -1.7 % and -2.7 % in 2050 in the 450 ppm and 400 ppm scenarios, respectively, is acceptable considering that the financial crisis managed to reduce GDP by -4 % in the EU27 within less than 2 years, while the impact of mitigation remains much more limited over a period of 40 years.

The impact on employment remains much more limited than on GDP, of the order of between +0.2 % and -0.3 % of employment change by 2050. There is considerable variation between economic sectors. Agriculture and industry gain employment because of the increased use of biomass and the mitigation investment into all kinds of machinery and electric appliances, but energy and other market services loose in employment. The energy sector losses because of the reduced demand for energy and the service sector because of the price increase of services induced by the mitigation investment of the service sectors. It is important to note here that the service sectors face significantly higher price increases due to mitigation investment than the manufacturing sectors.

Two issues should also be explained that provide arguments for why mitigation policy could even have a positive economic impact on the EU27: (1) a dampening effect comes from increasing government debt due to reduced fuel tax revenues because of the efficiency improvements, and (2) the ASTRA model considers endogenously the impact of reduced energy expenditures of households on the investment demand of the energy sector, though this is in fact better handled by the bottom-up models and thus overestimates the dampening effect of this consumption shift. Both effects could be reduced e.g. in the first case the government could take actions to maintain their tax base e.g. by taxes on imports of products that are not subject to a climate mitigation policy in the producer countries and thus avoid the crowding out effect of increased government debt. The World Trade Organization (WTO) has just acknowledged that such a policy would be compatible with the current WTO agreements.

Comparing the cumulative amount of mitigation investment and savings of fossil energy imports between now and 2050 it can be observed that before 2040 the cumulative mitigation investments are significantly higher, but this is turned around by 2050 when the cumulative savings of energy imports are higher than the mitigation investment. This trend should continue after 2050 and constitutes a strong argument for mitigation in Europe, as it contributes to both the two major objectives of the EU: winning the battle against climate changes and securing Europes energy supply.

These conclusions are similar to those of the Stern Report Stern (2007), which come to an assessment of a GDP change of the order of -1 % for mitigation to stabilise the climate. The Stern report also makes the important point that world GDP losses due to climate change are estimated to be in the range -5 % or more of GDP. While the EU will probably have lower losses than some other regions of the world, this is still a strong argument for decisive, large scale mitigation action to avoid major climate change impacts. The analysis presented here reinforces the argument that the macroeconomic costs of large scale climate change mitigation are small, compared to the risks, largely because of the strong positive boost to investment in the EU.

14 The Effects of the Financial Crisis on Baseline Simulations with Implications for Climate Policy Modelling: An Analysis Using the Global Model E3MG, 2008-2012

Authors: Terry Barker, S. Serban Scrieciu[29]

This brief study explores the implications of incorporating the recent financial crisis event for simulating business-as-usual future developments in the global real economy with relevant consequences for modelling climate policy. The 2008 world financial crisis is having strong effects on the structure of the global economy with substantial, and arguably lasting, negative repercussions on economic growth, employment, investment, consumption and trade. The incorporation of such effects into baselines used in energy-environment-economy models is crucial for providing reliable simulations of mitigation measures and climate policy analysis. We incorporate salient aspects of the financial crisis and of policy responses into our overall E3 modelling framework, E3MG, used for climate policy scenario analysis. The E3MG model shows substantial differences in baseline trends when considering the crisis with important implications for the future modelling of energy systems and climate policy responses. However, the caveat here is that the data on the outcome of the crisis is changing fast, by the week, which complicates the modelling. Hence, the results should be treated as preliminary. This analysis provided is up to 2020 and is aimed at informing long-term climate-policy models that do not have the capacity to model short- and medium term economic collapse.

14.1 Introduction

The global economy has begun a severe contraction after the “Big Crunch” of 15 September 2008, when Lehman Brothers went bankrupt and the event confirmed that the global investment banks were essentially insolvent without government support. The contraction has progressed month by month, slowing after the first phase as the reduction in holdings of current stocks comes to an end, but expected to continue as consumers’ expenditure responds to lower real incomes. The current consensus is for a major reduction in global GDP for 2009, with every major industrial country in decline, and world trade falling more strongly.

[29] The introductory text of this chapter draws heavily on Barker (2009a). We would like to acknowledge valuable contributions from Hector Pollitt at Cambridge Econometrics.

This chapter considers how the crisis will affect greenhouse gas emissions, particularly in Europe, and how the solution to the economic crisis may or may not be positive for mitigating climate change. A positive outcome would take the form of the required co-ordinated intervention by world governments being focused on investment in low greenhouse gas options for climate change mitigation. A negative outcome would be if governments attempted to restore pre-crisis investment patterns, and continued the high-carbon production and consumption patterns that have led to the climate change problem from the beginning.

The outcome remains unclear, but a return to normal seems unlikely. The global financial system has been severely damaged and, according to our analysis as of May 2009, the fiscal stimulus so far is well below what is needed to restore the global economy to pre-2007 rates of capacity utilisation and growth. Not only does it appear that output will be lost across the global economy, but global growth may not return to earlier rates, because the banks' indiscriminate withdrawal of lending facilities has tended to damage the more innovative, and hence more risky, enterprises. In addition, the indications are that Europe will have a more severe recession than many other regions as a result of greater exposure of European banks to toxic debt and a less aggressive policy response in terms of fiscal stimulus packages. The money creation by the European Central Bank in June 2009 will not necessarily translate to more loans when the banks' own balance sheets need restoring to safe levels in terms of leverage ratios and safe assets.

It appears that too many countries are relying on the extra spending in the USA and China to pull them back to growth. And the "green" component of the stimulus is mainly in China, South Korea, with a smaller (proportionate) effort in the US. It may be even less in other countries. The green stimulus is also diffused across many worthwhile projects, especially in improving water supplies and quality, but with only a small and uncertain component specifically allocated to mitigating climate change.

This study is structured into five sections. The next section 14.2 discusses the causes and consequences of the twin financial and climate crises. Section 14.3 presents the E3MG modelling approach to the financial crisis. Section 14.4 discusses results in terms of the direct effects of the financial-led economic collapse on greenhouse gas emissions, GDP and employment in EU economies relative to the base case where such crisis is not considered. Section 14.5 concludes.

14.2 The financial crisis and the climate crisis: common traits

Both crises can be traced ultimately to unrestrained pursuit of monetary wealth by individuals and corporations, without consideration of the social consequences or environmental effects of their actions[30]. In the events leading to the financial crisis, now in turn leading to mass unemployment, existing regulations were weakened and new regulations opposed to promote profit in spite of obvious risks. And although the climate crisis has long been recognised by governments, vested interests have persistently lobbied to undermine political and scientific efforts to introduce policies to address the market failures in the asset and loan markets and assert social priorities and objectives.

The pursuit of self interest in a market economy is seen as a virtue by Adam Smith but, as Foley argues, this thinking is based on the fallacy that the pursuit is necessarily “guided by objective laws to a socially beneficent outcome” when instead it involves moral choices at both personal and social levels (Foley, 2006, p. xiii). The effects of the pursuit of self interest by the bankers are evident from the May report from the Washington-based Center for Public Integrity (2009). The report provides the evidence that the US investment banks were instrumental in promoting subprime lending in the US through specialised dealers, now mostly bankrupt, and in lobbying against regulation to curb the risky behaviour, with the banks profiting by the repackaging of the loans. The bankers profited personally by the banks’ generous bonus schemes, which operate even when the banks make record losses.

Similarly the self interest of those in the fossil-fuel industries, both producing and consuming the fuels, is evident in their unrestrained pursuit of profit in cases where the damages to future generations have become highly likely in the scientific terms of successive IPCC Reports. The lack of corporate restraint is obvious where no adequate global regulations or pricing of environmental damages is in force, such as in the development of bunkering facilities in northern Canada, in expectation of new shipping routes through previously frozen Arctic waters. The certain consequence of such a development is more soot deposits on the Greenland ice sheet and hence more melting, exacerbating the sea level rise as global temperatures rise.

These are instances of two massive market failures associated with systemic risks: (1) the market failure of the financial system when the banks fail to take account of the risk that house and other asset prices might fall over a period of years, despite much historical evidence of such falls, and hence undermine their solvency; and (2) the market failure associated with climate change, that is the use of the atmosphere as a free waste disposal for greenhouse gas emissions from burning of fossil fuels and biomass in market-induced

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30 See Barker (2008) for an analysis of the implications of the values embedded in the traditional economic approach to the climate crisis.

deforestation. Both crises are the outcomes of highly non-linear systems' failures leading to extreme events in the economy, e.g. the collapse of Lehman Brothers bank on 15 September 2008, and in the environment (such as climate-change-induced hurricanes). And both threaten the world's economies with catastrophic collapse.

The solution to both market failures is action on a co-ordinated global investment plan to decarbonise the economy, complemented by a combination of effective regulation and long-term pricing of risk, in the forms of international standards for banks in creating risky assets, a long-term and reliable global carbon price, and international standards for low-greenhouse-gas technologies and products to reduce the costs of mitigation. However, this paper is focused on the effects of the financial crisis on the real economy and greenhouse gas emissions and hence the interaction of the financial and climate crisis, rather than the solution to the problems. Such an analysis will help to inform long-term climate-policy models that do not have the capacity to model short- and medium term economic collapse.

Of course there are striking differences between the two market failures. The financial crisis has been sudden, starting in early 2007, although its roots go back to the financial deregulation begun in 1971 in the UK and USA. The climate crisis is very long term, since it is associated with the accumulation of greenhouse gases in the atmosphere rather than in the emission fluctuations from one year to the next, and the effects of the accumulation have timescales of hundreds if not thousands of years (sea level rise). The risks are also different: the financial risks lie in a collapse of trust in money with the consequent risks of unstable prices and global depression; the climate risks are of wild weather over the indefinite future. The other key difference in the crises is in their solutions. The financial crisis has required an immediate solution to prevent or manage the collapse of the insolvent banks. The climate crisis is slow and ongoing and has not required immediate action, and so it has been more easily delayed and weakened by special interests.

14.3 Modelling the financial crisis

14.3.1 Our E3MG modelling approach

E3MG is the latest in a succession of models developed for energy-economy and, later, E3 (energy-economy-environment) interactions at global level. It is very similar in structure to the E3ME model,[31] which follows from EXPLOR, built in the 1970s, then HERMES in the 1980s. Each model has required substantial resources from international teams and each model has learned from earlier problems and developed new techniques. Like its

[31] See www.e3me.com.

predecessors, E3MG is an estimated model, based on OECD, Eursotat, UN, IMF and IEA data; it also includes data sets collected from national sources. It encompasses both long-term behaviour and dynamic year-to-year fluctuations, so that it can be used for dynamic policy simulation and for forecasting and projecting over the medium and long terms. As such, it is a valuable additional tool available for economic, energy and environment policy analysis at the global level.

The model represents a different approach to the modelling of technological change in the literature on the costs of climate stabilisation. It is based upon a "new economics"[32] view of the long-run, drawing on Post Keynesianism, adopting a "history" approach of cumulative causation[33] and demand-led growth, and incorporating technological progress in gross investment enhanced by R&D expenditures. Furthermore, E3MG is a hybrid model in the sense that it integrates a bottom-up energy technology sub-model with energy technologies explicitly modelled[34] within a top-down detailed macroeconomic framework. The latter incorporates a dynamic simultaneous system of 22 sets of behavioural time-series equations to explain demand-led growth, as well as prices, energy demand, wages, employment, housing investment and trend output for each industrial sector. Overall, compared to the existing modelling literature targeted at achieving the same goals, we argue that the advantages of the E3MG model lie in three main areas. First, the detailed and disaggregated nature of the model (estimated on annual data spanning 1970–2006 across 20 regions, 42 sectors, 28 consumer spending categories, 12 fuels and 19 fuel users) allows the representation of fairly complex scenarios.[35] Second, the econometric grounding of the model makes it better able to represent the behaviour of energy-economy systems. And third, by linking the top-down macro-econometric structure of the model with a bottom-up energy technology sub-model (explicitly modelling 28 energy technologies), a two-way feedback between the economy, energy demand/supply and environmental emissions is achieved. This represents an undoubted advantage over other models, which may either ignore the interaction

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32 "New Economics" is concerned with institutional behaviour, expectations and uncertainty as opposed to traditional economics with its emphasis on equilibrium, mathematical formalism and deterministic solutions. We use the term to include various heterodox approaches including Post Keynesian, evolutionary and institutional economics. This new economics approach (see footnote 2) is currently being developed for future research and papers. However, some elements of new economics have already been explored in Barker (2008) and Barker, Scrieciu and Taylor (2008).

33 "Cumulative causation" refers to a dynamic institutional process in which various factors combine to create a vicious or virtual circle to strengthen an initial effect (Berger, 2008). Kaldor (1957, 1972, 1985) developed the economic theory based on increasing returns and agglomeration economies.

34 The energy technologies and the equations underpinning the ETM sub-component of E3MG are also extensively discussed in Barker et al (2005, 2006), Köhler et al (2006) and Barker et al (2007) for the E3ME model, the European counterpart of E3MG.

35 The model's regions are linked by trade equations based on bilateral trade matrices, and the sectors are linked by 2000-based input-output tables.

completely, or only assume a one-way causation. The advantages of using the hybrid approach have been reviewed in Grubb et al (2002) and Hoogwijk et al (2008).

Three main mechanisms describe the key features of accounting for endogenous technological change in the version of E3MG we used. First, at the macro-level, sectoral energy-demand, import and export-demand, and employment equations include indicators of technological progress in the form of accumulated investment and R&D. Second, as described below, the ETM incorporates learning-by-doing through regional investment in energy generation technologies that reduce in cost depending on global-scale economies. And third, extra investment in new technologies, in relation to baseline investment induces further output through a Keynesian multiplier effect and therefore more investment, trade, income, consumption and output in the rest of the world economy. However, further changes can be induced by policy; hence the term induced technological change.[36] For example, feed-in tariffs for renewables (as used in Germany) will alter relative prices such that investments in renewable technologies are stimulated and, depending on their learning curve characteristics (and Keynesian multiplier effects at the macro level), they will lead to higher adoption rates. The effects of technological change modelled in this way may turn out to be sufficiently large in a closed global model to account for a substantial proportion of the long-run growth of the system. Further details of the E3MG model are extensively discussed in Barker et al (2005, 2006, 2008) and Barker and Scrieciu (forthcoming).[37]

14.3.2 Scenarios simulating the financial crisis

This study explores the impact of the ongoing financial crisis and economic downturn on business-as-usual trends up to 2020 (Pollitt and Barker, forthcoming). The financial crisis (labelled “crisis” scenario) was modelled through a baseline (defined here as “trend” representing business-as-usual projections in the absence of a crisis) plus a series of sub-scenarios. The latter simulating the crisis element fall into two groups: aspects of the crisis and current policy, i.e. announced policy stimulus across countries. The baseline without the crisis “trend” scenario is very similar to that reported for ADAM M2 in Knopf et al (forthcoming) and Barker and Scrieciu (forthcoming). At the European country level, baseline “trend” assumptions (e.g. oil prices and population) are discussed in detail in the ADAM deliverable report M1.1.[38] In other words, the baseline set of projections excluded the effects

36 The term induced technological change (ITC) refers to further changes in technological progress (i.e. endogenous technological change) that are induced via policy measures (Barker et al., 2006).

37 The model manual for E3MG is currently under development. However, the manual for the European E3ME model, which is similar in structure and econometric method, is freely available online (Cambridge Econometrics, 2007).

38 Deliverable D-M1.1 for the ADAM project (2007) “Report of the Base Case Scenario for Europe and full description of the model system”; contributed with E3ME modelling results; E. Jochem

of the financial crisis. These projections were formed by allowing E3MG to solve year by year over the forecast period. As the estimated output for 2008 at this time was only slightly below trend, the baseline projections roughly show a continuation of growth rates from before the financial crisis.

The inputs referring to the financial crisis being inserted into the “trend” baseline have been carefully defined based on economic theory, historical precedent and the judgement of the modelling team. The crisis has been modelled in order to capture a specific aspect of observable behaviour caused by the downturn, as well as a summarised version of current policy reactions (e.g. fiscal stimulus packages) towards the end of March 2009. In other words, each of the sub-scenarios forming the “crisis” baseline was designed to demonstrate a specific aspect of observed outcomes caused by the crisis. The model results indicate the direct plus indirect impacts of these behavioural shifts.

The behavioural aspects of the financial crisis being modelled in E3MG include:

- Banks cutting back on expenditure, both on capital (e.g. buildings) and labour, in an attempt to protect their own businesses. Investment by the banking sector was assumed to fall by 25% and employment is reduced by 12.5% over 2009-11 compared to baseline “trend”.
- Banks encouraging higher savings rates in order to protect their balance sheets, with a resulting net impact of 0.5 percentage points increase in household savings ratios in 2009;
- Banks reducing lending to business despite stimulus from policy makers, yet again in order to protect their balance sheets. The resulting macroeconomic impacts is assumed to be a reduction in investment by businesses of 5% in 2009-11
- Returning to “normal” (historical averages) savings rates, as banks no longer making available cheap credit. Savings rates are assumed to increase 7-9% (historical level in 2000) in the US, Japan and Western Europe (except Germany, where rates were already high)
- Emerging disincentive to invest created by an uncertain and unstable economic environment particularly with reference to future probability (fuelled by high volatility in asset and commodity prices). It is assumed here that the private-sector business investment (to include R&D) is permanently cut by around 40% over 2009-2011.
- Global commodity prices reacting and declining, with oil prices assuming to fall from baseline values to $60/bbl in 2009 and oil-producing countries cutting back on investment as a result.

M1 Work Package leader (Fraunhofer Institute of Systems and Innovation Research); www.adamproject.eu.

Furthermore, the “crisis” baseline scenario as modelled in E3MG includes a summarised version of current policy measures (“fiscal stimulus” towards the end of March 2009 collected as inputs to the model. The focus in on the effects on the real economy so we do not include the large sums of money injected into the global financial system. Central bank interest rates were updated with the latest available information. Two main sources were used for this purpose: Prasad and Sorkin (2009) and HSBC (2009) with additional information (when needed) from the Economist website. Much more detail on the subset of scenarios forming the “crisis” baseline, as well as on the underlying thinking may be found in Barker (2009b) and Pollitt and Barker (forthcoming).

14.4 Impacts of the financial crisis and recession

Before presenting the results, we would like to stress that the results should be treated as preliminary. This is because the data on the outcome of the crisis is changing fast, by the week, which complicates the modelling. Furthermore, though the model is based on historical data, the crisis represents a deep change in economic structure not captured in the time series inputted into E3MG. As a result, the E3MG model is constantly undergoing development to incorporate the flows of new information on the recession.

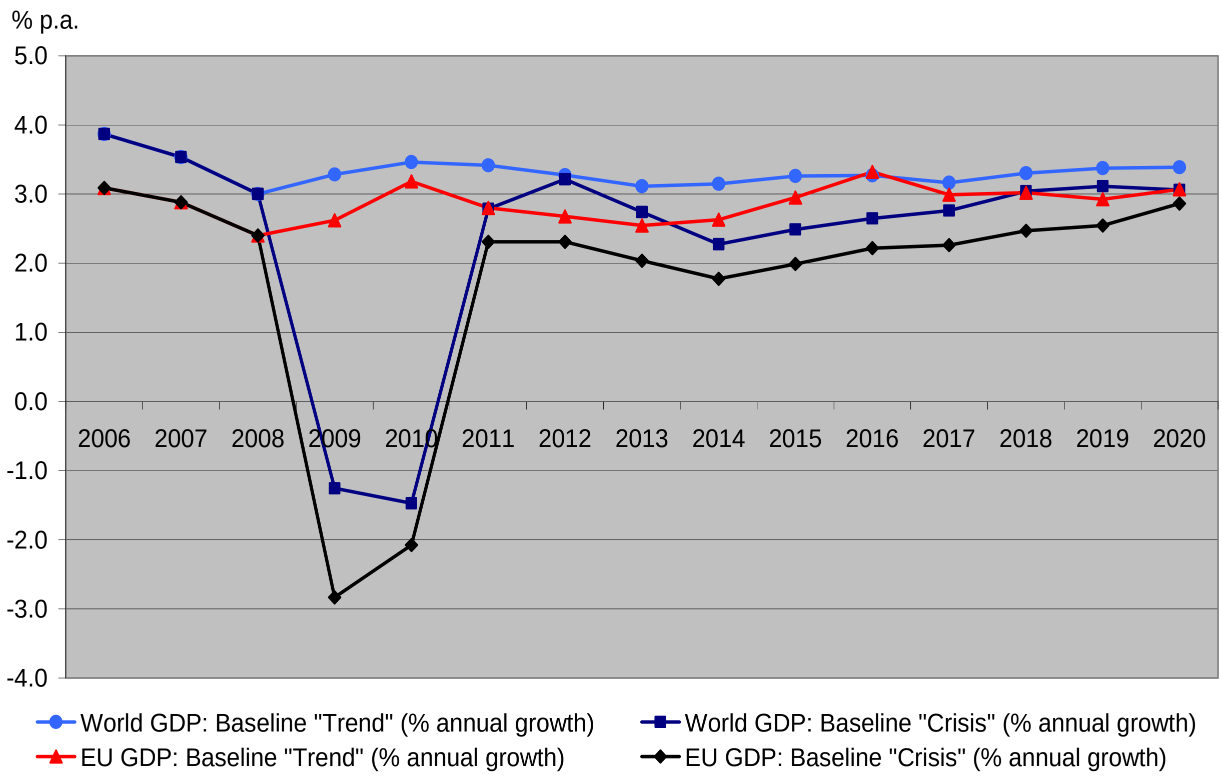
With these caveats in mind, preliminary results are displayed in Table 14-1showing the growth rates on GDP in major EU economies, the EU and the world both on trend, as adopted in the ADAM baseline, and in the crisis scenario. Figure 14-1 illustrates the table. It is clear that the assumptions and modelling indicate that GDP will be lost not only in the short term but also in the long term. Growth rates are expected to be lower after the economies return to more normal rates of growth after the crisis is resolved. GDP growth rates across all EU economies displayed in Table 14-1 are shown to be below “trend” rates corresponding to a situation where the crisis would not have emerged. Such outcomes were evident in the aftermath to the Nordic economies’ 1992 financial crisis (Ergungor and Thomson, 2006; Ergungor, 2007; Ergungor and Cherny, 2009). In the short term, there is a dramatic drop in world growth rates and across EU economies (Figure 14-1), with world GDP growth rates projected at -1.3 and -1.5 percent, and EU growth rates at -2.8 and -2.1 percent, for 2009, and respectively, 2010. Across most large economies, negative growth rates are expected to persist in the next two years, with the rates turning positive only after 2010. The fall in output is less driven by the activities of the banks by themselves, but more by the effects of the behavioural changes by industry and households. Looking at GDP impacts across EU countries, Italy, rest of EU-15 and UK appear to be the most affected. The former two have declines in output, mainly due to the corrections applied to their savings ratios, whereas the UK (as in the case of US) has both a large financial sector and a savings ratio below that is a long way below historical average.

Germany also experiences a significant reduction in output mostly as a result of produce investment goods or components of these goods being negatively affected.

Table 14-1: GDP Annual Growth Rates across EU regions and the world: Baseline "Trend" versus "Crisis"

		2008	2009	2010	2011	2012	2015	2020
Germany	Trend	1.5	1.8	2.1	1.6	1.8	1.7	2.4
	Crisis		-1.2	-2.2	1.0	1.8	1.1	2.3
UK	Trend	1.3	3.0	3.2	3.1	2.8	2.6	2.4
	Crisis		-2.7	-0.6	2.8	2.9	1.7	2.1
France	Trend	1.0	2.3	2.9	1.7	1.3	2.5	2.0
	Crisis		2.3	-1.1	1.5	1.1	1.3	1.5
Italy	Trend	0.3	1.6	2.2	2.6	2.0	2.3	2.0
	Crisis		-5.0	-1.8	2.3	1.1	1.3	1.0
Rest of	Trend	1.5	3.6	4.3	4.1	4.0	4.3	4.9
	Crisis		-6.2	-4.0	3.1	3.3	3.6	4.7
EU-10	Trend	4.1	2.1	4.2	3.0	3.6	3.6	5.3
	Crisis		-2.1	-0.4	4.4	3.8	1.9	4.8
EU	Trend	2.4	2.6	3.2	2.8	2.7	2.9	3.1
	Crisis		-2.8	-2.1	2.3	2.3	2.0	2.9
World	Trend	3.0	3.3	3.5	3.4	3.3	3.3	3.4
	Crisis		-1.3	-1.5	2.8	3.2	2.5	3.1

Source: E3MG modelling results



Source: E3MG modelling results

Figure 14-1: World and EU GDP growth rates: Baseline “Trend” versus “Crisis”

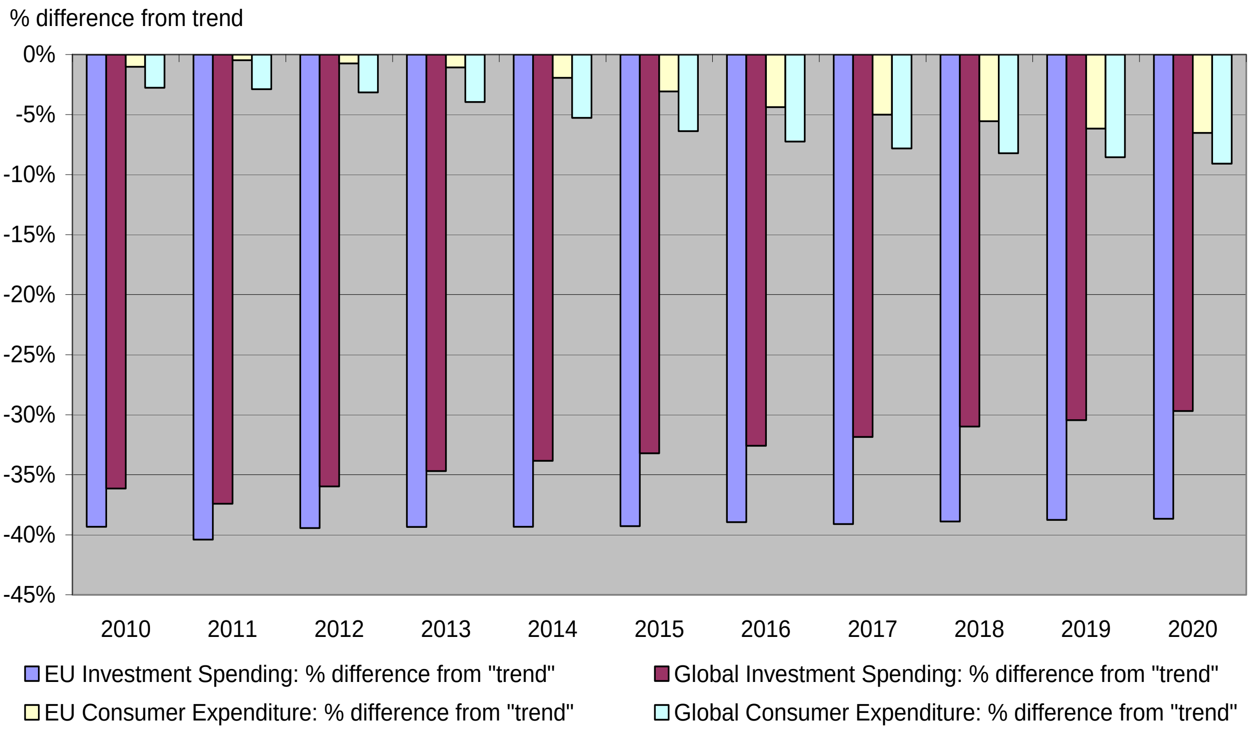
At the aggregate sectoral level, the manufacturing and construction sector as well as agriculture appears to be worst hit by the recession (see Table 14-2). The manufacturing and construction sector is the worst affected mostly because it comprises activities that produce investment goods and the more basic manufacturing sectors that produce inputs to the industries. The agricultural sector also suffers particularly due to a decline in export activities partly due to declining world food prices.

Table 14-2: Sectoral output effects across main activities for the EU E3MG regions: effects in 2020: % difference from baseline "Trend"

	Germany	UK	France	Italy	Rest of EU-15	EU-10	Total EU
1. Agriculture	-24.4%	-16.7%	-10.2%	-26.4%	-27.2%	-7.8%	-23.3%
2. Energy	-5.5%	-4.4%	-4.0%	-12.2%	-7.5%	-3.8%	-6.6%
3. Manufacturing & Construction	-26.0%	-25.3%	-13.7%	-28.9%	-39.1%	-23.4%	-29.7%
4. Services (incl. Transport)	-4.8%	-14.3%	-8.2%	-9.4%	-15.7%	-9.5%	-11.1%
Total	-13.6%	-16.3%	-9.8%	-17.6%	-25.4%	-14.2%	-17.9%

Source: E3MG modelling results

Furthermore, as clearly illustrated in Figure 14-2, the main driver of the fall in GDP is the investment spending component. This is due to the nature of the financial crisis and how this has been modelled in E3MG, i.e. the collapse of the banking sector affecting first and foremost business sector through deteriorating lending and a generally depressed confidence in the investment environment. The fall of EU (and developed economy) investments as explained in section 3.2 is largely an exogenous inputted shock into the model, which amounts to around 40% from baseline "trend" levels. Global investments decline by less, as developing economies are assumed to be less affected by the nature of the crisis. By contrast, consumer expenditure declines by less during 2010-2020, partly as a reaction to falling prices and unstable economic environment, with consumers preferring to increase their saving rates as an "insurance" strategy against any potential future job losses or a decline in real wages. As the negative effects on employment lag behind GDP effects (as shown below), consumer spending effects also become more visible in latter years, as job prospects gradually deteriorate.



Source: E3MG modelling results

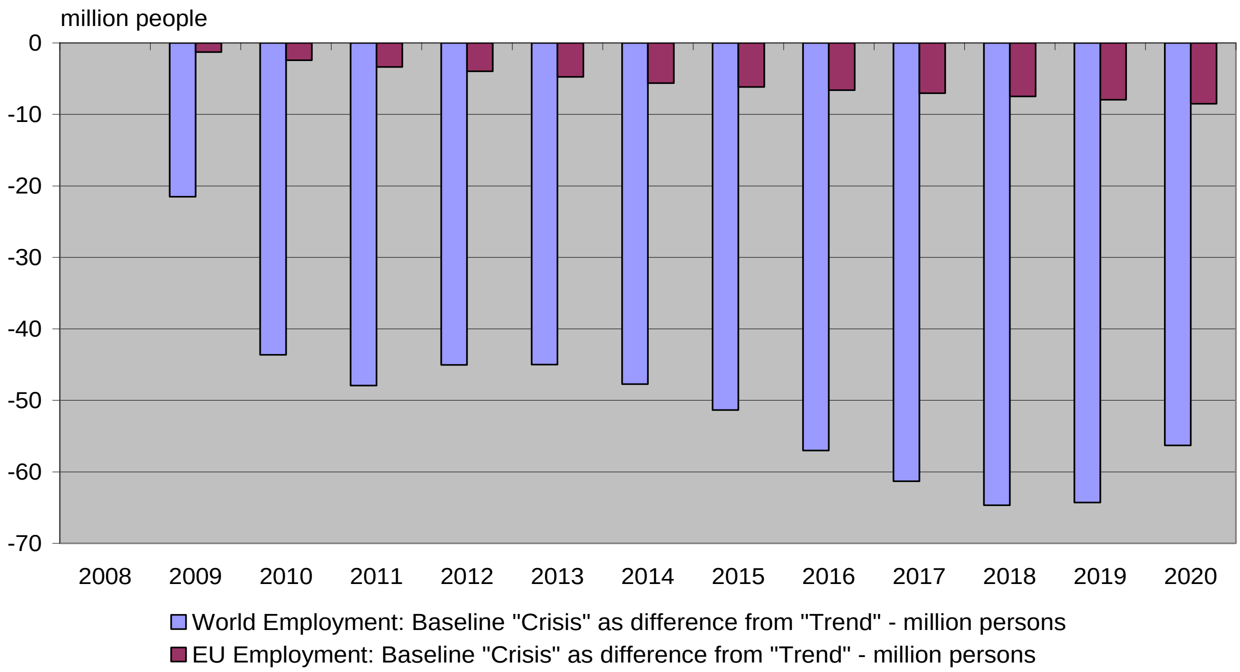
Figure 14-2: Impacts of the recession on EU and Global Investment and Consumption: % differences from baseline "trend", 2010-2020

The crisis is also expected to lead to substantial unemployment across the global economy, though the levels of reduction in GDP are expected to be much greater than the magnitude of employment cuts. For example, in 2020, GDP levels are around 15% at the global level and 13% for the EU lower in the crisis relative to baseline trend, whereas the corresponding reduction in employment is projected at 3.4% and 2% for the world, and respectively EU (see Table 14-3). Figure 14-3 shows how the unemployment increase lags behind the fall in output, because employers tend to hold on to their workers at the beginning of a depression in the hope that the recovery will emerge. However, as the downturn progresses, this labour hoarding unwinds and hysteresis effects emerge to make the unemployment more persistent. Hysteresis is a long-observed feature of the labour market: as unemployment persists, the unemployed become more and more unemployable as they adapt their life-styles to being unemployed. The crisis is so severe that we expect the higher unemployment to last for 10 years and more. In Table 14-4, absolute changes in terms of millions of people losing employment due to the economic recession are being simulated for the world and EU. As previously mentioned, E3MG indicates towards a gradual increase in employment cuts. The number of people becoming unemployed reaches around 60 million people at the global level and around 8 million people in the EU, in the year 2020. However, unemployment effects are only partly modelled in the version of E3MG used in this report, as there are no wage adjustments in response to unemployment and the mechanisms for employment to come back are not fully captured. For this reason, unemployment effects are only reported at an aggregated EU level. However, it is expected that impacts on employment tend to follow those on output, with the exception of countries where output has fallen and labour markets are flexible (e.g. UK), where employment effects are likely to exceed output impacts.

Table 14-3: EU and World GDP, Employment and CO_2 Emissions Effects in 2020: % difference from baseline "Trend"

	EU	World
GDP in 2020: "Crisis" as % difference from "Trend"	-15.4%	-12.9%
Employment in 2020: "Crisis" as % difference from "Trend"	-3.4%	-2.0%
Total CO_2 Emissions in 2020: "Crisis" as % difference from "Trend"	-10.8%	-5.6%

Source: E3MG modelling results



Source: E3MG modelling results

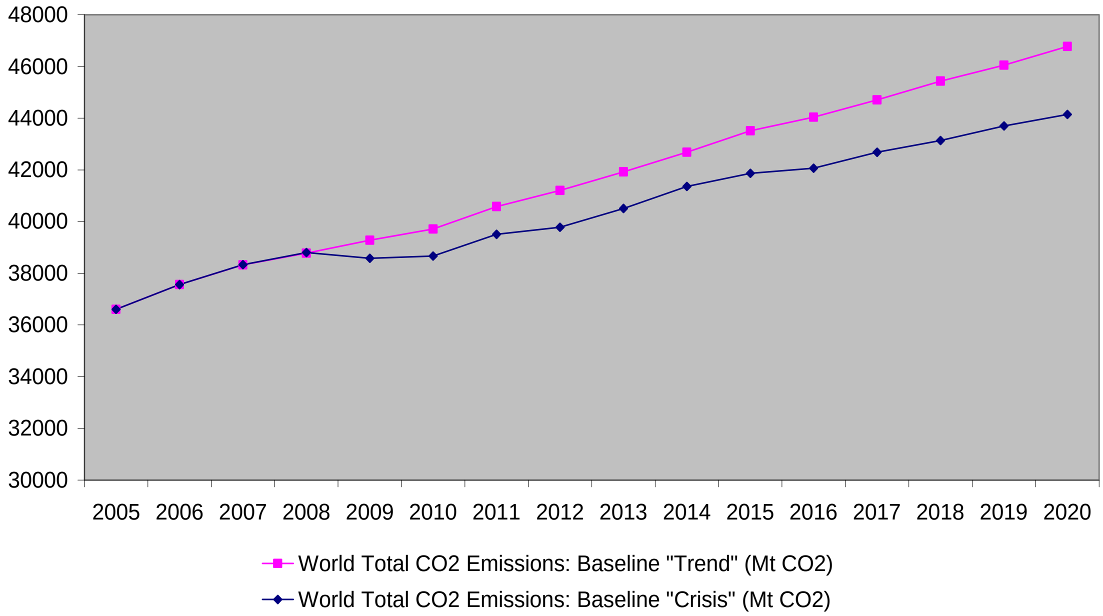
Figure 14-3: World and EU Employment effects: "Crisis" as difference form "Trend", million persons per annum, 2005-2020

Table 14-4: Annual World and EU Employment effects in the “crisis” scenario as difference from “trend” (million persons), 2008-2020

	World Employment: Baseline "Crisis" as difference from "Trend" - million persons	EU Employment: Baseline "Crisis" as difference from "Trend" - million persons
2008	0.0	0.0
2009	-21.5	-1.3
2010	-43.6	-2.4
2011	-47.9	-3.3
2012	-45.0	-4.0
2013	-45.0	-4.7
2014	-47.7	-5.6
2015	-51.4	-6.2
2016	-57.0	-6.6
2017	-61.3	-7.0
2018	-64.7	-7.5
2019	-64.3	-7.9
2020	-56.3	-8.5

Source: E3MG modelling results

Figure 14-3 shows the effects on global CO_2 emissions. There is expected to be a major reduction below trend levels, such that CO_2 emissions are over 10% below baseline levels by 2020 for EU as a whole, and around 6% below business-as-usual trends at the world level (see Table 14-3).



Source: E3MG modelling results

Figure 14-4: Total CO_2 Emissions for the World and EU: Baseline "Trend" versus "Crisis", 2005-2020

14.5 Discussion and conclusions on macro-economic level

The collapse of the global investment banks, with the consequent reduction in lending, instability of prices and falls in investment and trade, has led to reductions in industrial output, personal incomes, household expenditures, and hence in energy use and in greenhouse gas emissions. Since there is a data lag in the reporting of emissions, it is not yet clear how large the reduction will be, but it is likely to undermine earlier scenarios of continuous increases in emissions assumed in IPCC reports and other scenarios. However, at the same time, the global price of oil has fallen substantially from the highs in 2008 of $140/bbl to $50/bbl or lower in April 2009. Lower oil, gas and coal prices are encouraging a switch back to fossil fuels in energy demand, offsetting the effect of the reduction in overall energy demand on CO_2 emissions.

The long-term effect will depend on the length and depth of the global recession. During the Great Depression, from 1929-1934, global CO_2 emissions fell by 25%, but in the current crisis, which is expected to last at least until 2012, the energy system is substantially different, with coal use largely confined to electricity generation, and transportation a much larger share of overall energy demand. Both sources of demand for fossil fuels are likely to be more responsive to the fall in demand than in the Great Depression, but the industrial use of coal, which collapsed in the US 1929 to 1934, is much less important now. In addition, the lower relative cost of coal, the dominant source of CO_2 emissions, and the greater potential for substitution towards coal in modern electricity generation, may lead to more use of coal instead of gas and capital-intensive renewals, especially in developing countries. In other words it is not yet clear how much CO_2 emissions will fall over the next year or so. Much depends on the responses of developing country governments to the crisis. If they take the opportunity to modernise or replace their polluting coal-fired electricity plants, switching to gas and renewables, then the emissions may fall rapidly.

Our analysis uses a global energy-environment-economy model (E3MG) to assess these effects and finds that the long-term effect of the crisis is to reduce CO_2 emissions by some 10% below a trend baseline by 2020. However, the recession is just beginning and it is far from clear how governments will react in their policies towards the energy sector, and whether the old coal-burning plant will be retired never to return. CO_2 emissions could well be much lower relative to trend than reported above, and new data needs to be incorporated in future simulations of E3MG to model this. An uncertainty analysis on modelling the financial crisis to account for such ranges is expected to be carried out in the next phases of using the E3MG model.

14.6 Impacts of economic crisis on sectoral level

Authors: Wolfgang Schade, Giacomo Catenazzi, Tobias Fleiter, Anne Held, Martin Jakob, Eberhard Jochem, Ulrich Reiter, Hal Turton.

This section briefly transfers the impacts identified on the macroeconomic level in the previous sections onto the findings obtained by the bottom-up models of the ADAM-HMS. For each sectoral analysis a brief conclusion on the potential impacts of the crisis on energy demand and GHG emissions in the specific sector is drawn. Given the uncertainty reported for the macro-economic results in the previous sections (-15.4% loss of GDP in 2020 compared with trend) and the introduction of economic stimulus programmes the sectoral analyses below assumed a GDP loss of about -10% until 2020, i.e. the level of GDP in the EU27+2 would be -10% lower than in the Reference Scenario, without the crisis.

14.6.1 Impact of crisis on residential sector

The impact of the economic crisis on energy demand and CO_2-emissions of the residential sector differs between the Reference scenario and the 2-degree scenario.

In the Reference case without stringent mitigation policy energy demand and direct and indirect greenhouse gas emissions are affected by the disposable income of households and building owners, which would be reduced. Moreover the financial sector and thus the market for loans and mortgages lacks capital or pursues a more conservative policy which results in higher capital costs (as higher risk premiums are required) and rerstricted access to capital. Further, immigration could be negatively affected which would lead to a slightly lower population growth.

These economic boundary conditions have several effects on both physical drivers and specific energy demand levels. These effects oppose each other to a certain extent.

- On the one hand side energy demand and GHG emissions are mitigated due to attenuated construction of new building and due to new flats and houses which will be smaller in size. Energy consuming appliances including those to adapt to climate change are purchased to a lower degree and are smaller in size.
- On the other hand, energy demand and emissions are tend to increase as building owners and consumers are more reluctant to invest in more energy-efficiency or renewable energies. Indeed, both energy-efficient buildings and appliances and renewable energy technologies are characterized by higher up-front costs which might be perceived as a more pronounced barrier in times of economic crisis. In periods with economic uncertainties owners and consumers are usually more risk averse and higher (implicit) discount rates negatively affect the economic viability of such investments or purchases. This effect is intensified if additionally prices of (fossil) energies are negatively affected.

Note however that some of the arguments also might turn out the other way round. For instance, financial markets, investors and consumers might shift their priorities away from shares and other financial products and into more down-to-earth investments such as the real estate sector, individual homes, and energy-efficiency and renewable energy technologies. In this case the (physical) drivers are mitigated less and energy-efficiency und renewable energy choice are affected less than described above. In any case it can be affirmed that the effect of the financial and economic crisis will be limited (some few percentage points of investment at the most).

In the Mitigation scenario the second argument of reduced levels of energy-efficiency and renewable energies gains weight as compared to the Reference scenario. However, in addition to the effects as described above, the impact of the economic crisis in the mitigation scenario also strongly depends on the reaction of policy makers. Remember at this stage that quite broad and intensive policy measures underly the Mitigation scenario. Two outcomes are conceivable:

- Either policy makers react conservatively and cancel policy measures or lower their intensity in the light of the economic crisis. In this case mitigation intensity would be lower than projected in the 2°C scenario.
- Or policy makers view mitigation measures as an economic and fiscal opportunity and foster policy measures. Indeed energy-efficiency measures and investments in renewable energies are more labour intensive as compared to imported fossil fuels. Linking taxes and levies to the consumption of non-renewable resources rather than on labour or income results in more stable fiscal incomes.

To conclude, the economic crisis may negatively affect energy demand and GHG emissions, but to a large extent the impact also depends on the actual choices of policy makers, building owners, financial institutes and consumers and whether they understand the economic crisis as an opportunity to shift their preferences in direction to a more sustainable path.

14.6.2 Impact of crisis on services sector

Buildings are a major contributor to energy demand and GHG emissions of the service sector as is the case in the residential sector. Hence, there are some similarities regarding the impact of the economic crisis on energy demand and emissions (see section 14.6.1). The economic (and financial) crisis curbs the disposable income (i.e. value added, profits) of both of the private and the public sector and reduces the availability of capital. As in the case of the Residential sector these changes in the economic boundary conditions may affect quantitative (physical) drivers, energy use and energy-efficiency levels and, possibly, the attitude and priorities of policy makers and other actors that determine policies, investments and energy use.

Quantitative drivers are negatively affected by lower economic growth, but only to a limited extent. Indeed it can be assumed that labour force in the service sector is slightly negatively affected on the long run by the lower level of GDP though the floor area of buildings as a long lasting capital good is less attenuated. To a certain extent also the use of energy might be reduced due to lower employment and due to a more careful use of resources. Note however that energy use is rather related to buildings (and floor area) than to the number of building users which limits this latter effect.

On the other hand the intensity of investments into energy-efficiency and the shift towards renewable energies might be lowered to a certain extent, since upfront add-on costs are often rather avoided in times of economic uncertainty.

Hence, in the case of the service sector, the overall impact on energy demand and emissions is presumably much less than the impact on economic growth, especially in the reference scenario. In the case of the 2-degree scenarios this statement still holds unless it is assumed that policy measures are cancelled or strongly weakened in their intensity.

14.6.3 Impact of crisis on industry sector

Although the economic crisis was not explicitly modelled in the scenarios, the main impacts on industrial energy demand as well as GHG emissions are described in the following.

Of all the sectors, the industrial sector shows the biggest impacts from the economic crisis on the emission level. This is mainly due to the fact that if the value added decreases, physical production also goes down and thus also energy demand and GHG emissions. In other words, there is a strong correlation between economic activity and level of emissions in industry. This correlation is even stronger, when considering structural effects with industry, as it can be observed that the demand for as well as the production of the most CO_2 intensive products like steel or cement may decrease significantly more than the other industrial sectors. This is particularly true in the short term. Effects in the longer term are mainly determined by the lower growth path of the economy that directly effects the emission level as described above. Another long term effect comes from the investment behaviour of companies, as in times of economic downturn they are reluctant to invest in new and more efficient production facilities and consequently the annual improvements in technical energy efficiency are lower. However, this effect is slightly offset by the fact that during the economic crisis mainly the least efficient and productive plants are closed, while they are replaced during times of the following economic upturn by new and more efficient ones.

To conclude, if in the long-term, the growth of industrial value added is lower by about 10% in comparison to the development without the crisis (e.g. up to the year 2020) this would probably have an effect on the emission level in a similar order of magnitude or somewhat less to to the different counteracting effects mentioned.

14.6.4 Impact of crisis on transport sector

The transport sector was hit similarly heavily by the economic crisis to the industry sector, in particular as industry sectors with high levels of transport demand were hit hardest (e.g. steel procuers, car manufacturers, some bulk chemicals). Manufacturers of trucks reported losses of sales of new trucks of up to -80% for some months in the first half of 2009. The German railway company DB had to rent 170 km of tracks just to park 8000 freight wagons at the end of 2008 that were not needed anymore due to the crisis as rail freight transport lost some 20 to 30% of demand. About 15% of world merchant fleet is currently idling in front of the ports, because of lack of demand in particular for container transport.

Obviously such a reduction in freight transport demand will reduce the GHG emissions of freight transport by a similar magnitude i.e. by about -10 to -25% compared with a case without the crisis. Since freight transport accounts for about one third of GHG emissions this would imply a reduction of -3 to -8% of transport GHG emissions. This situation would be largely maintained with the assumption that GDP remains -10% below the Reference Scenario development. Only in case of catch-up of GDP would the GHG emissions also catch-up to the levels in the Reference Scenario. A second issue concerns technical progress. The retiring of vehicles will start with the less efficient and thus more costly ones such that the specific emission levels of the remaining fleet should be lower than without crisis. This effect should be permanent, given that we assume a permanently lower level of GDP.

Passenger transport is affected less than freight transport. However, the main drivers of passenger transport, i.e. income and employment, are also expected to be reduced in the medium-term by a permanent crisis with a loss of 10% of GDP. Secondly, some of the economic stimulus packages include scrappage schemes providing subsidies for old car scrapping in case of the purchase of a new car. This leads to a renewal of the fleets and thus should lower the specific consumption and GHG emissions, though in most schemes the option, which would have been very promising in terms of contibuting to climate policy, to require that the new car is fuel and GHG efficient, was not considered. Thus the potential to save GHG was reduced. Overall it can be expected that also passenger transport would reduce its GHG emissions by -5 to -10% compared with a no-crisis scenario.

Overall, it seems that transport should reduce its GHG emissions by about -4 to -10% in a scenario with economic crisis compared with a no-crisis scenario.

Finally, it should be pointed out that the transport sector required government support for a number of mitigation measures (e.g. subsidies for electric vehicles, support of R&D into vehicle efficiency and batteries), which might not be provided in a crisis scenario, in which governments are facing high debt due to funding economic stimulus programmes and reduced tax revenues, because of the crisis. This could reduce the potentials to save GHG in the 2-degree scenario.

14.6.5 Impact of crisis on energy conversion sector

The ongoing economic crisis potentially has several impacts on the energy conversion sector. In our results for the Reference Scenario and 2-degree Scenarios (see chapter 11) we show the need of investments in the range of €500-600 billion until 2020 to install additional generation capacity and to build up renewable capacities. Due to the economic crisis, these investments are likely to be delayed given limited availability of finance. In particular, projects for riskier technologies (i.e., where the technologies are less mature or dependent on uncertain government subsidies) are even more likely to be postponed or even canceled. To balance final energy demands, existing power plants with lower efficiencies and higher emissions per kWh are therefore likely to be operated for longer and retired later, resulting in higher emissions.

The impact of the crisis on projects for renewable generation capacities remains unclear for the moment. Private investors are likely to postpone investments in renewable electricity generation if there are increasing doubts about whether governments will maintain policy support, such as assuring stable feed in tariffs or subsidies for these costlier technologies. Since governments are likely to be under pressure to reduce budget deficits, it is unclear if measures supporting renewables are likely to be maintained. Similarly, the higher energy costs for consumers from feed-in-tariffs may become difficult to justify in the face of reductions in income. On the other hand, renewables may find additional support through various ‚green’ financial stimulus packages under discussion or in the process of implementation.

It was shown within the ADAM project that greenhouse gas emissions already need to be reduced in the short term to mitigate climate change which then leads to the introduction of effective emission prices. Important in this respect is a timely international agreement on stringent abatement targets (and hence high CO_2 prices) which could be either achieved by emission taxes or a cap and trade system. In the context of the crisis, governments may be more willing to embrace such measures since they may provide an important source of additional revenue, to make up for the shortfalls in income and corporate tax revenue, and higher outlays. However, it will be critical to address concerns regarding the introduction of new taxes or levies during a time of economic weakness. It will also be necessary to ensure that a large share of any carbon tax revenue is reinvested in the energy conversion sector to facilitate the change to a more sustainable energy system.

It is also worth mentioning that the drop in economic output from the crisis is leads to reductions in demands for electricity and fossil fuels across the industry or services sectors (see above sections). This in itself is likely to lower annual emissions at least during the crisis and shortly afterwards. This may persist longer if the recovery is slow and the long-run growth potential of the economy is lower than anticipated prior to the crisis. Accordingly, the high emission levels seen in Europe before the crisis may take some time to be reached again. At the same time, however, the lower rate of economic growth is likely to coincide with a slower rate of technological innovation and deployment of new technologies, leading to a slower reduction in energy intensity.

14.7 Conclusion on impacts of crisis on the sectoral level

The sectoral analysis concluded that the economic crisis will reduce the GHG emissions in the short-term and under a scenario of a permanent loss of GDP by -10% also in the long-term. The sectors reducing GHG emissions most due to the crisis would be industry and transport, which could reduce GHG emissions in the same order of magnitude as GDP.

In some cases, the crisis itself as well as the economic stimulus programmes will contribute to permanent reductions of GHG emissions by putting high polluting vehicles of facilities out of service when their capacity is not needed anymore due to the crisis as well as by funding the renewal of vehicle fleets.

However, for the 2-degree scenarios there is also the major risk that lack of funding due to the crisis (e.g. because of reduced government budget) and increased risk averseness of investors or households will hamper the implementation of measures required to achieved the GHG emission reductions. This means, if policy does not put particular emphasis on mitigation policy the “conventional” way of handling the crisis would significantly reduce the chance that such 2-degree scenarios can be achieved.

One option to link mitigation policy and crisis managment would be to follow the idea of the “Green New Deal”, which is to always link the economic stimulus with the requirement to introduce green technologies and GHG lean processes.

15 Conclusions and policy recommendations

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The broad message of the sectoral analyses performed for Europe using the ADAM Hybrid Model System (ADAM-HMS) and the POLES model is the same: a pathway to reach the 2°C target is technologically feasible. However, there is no silver bullet in climate policies to achieve the goal and to optimize costs and benefits. All the options of emission reductions will have to be forcefully activated and sustained over a long time horizon. A broad package of policies to stimulate technological change as well as behavioural change has to be implemented by the EU, the Member States, municipal governments and numerous actors from the public and the private sectors.

The above fundamental outcome is explored in detail in the following sections. The conclusions start with a section on methodological conclusions followed by the conclusions for the sectoral level, the macro-economic level and the impact of the crisis on climate policy. The final section presents policy recommendations.

15.1 Conclusions and recommendations on the methodology

Our work tackled a number of important methodological challenges, some of them for the first time in that detail in climate policy analysis. A clear advantage of the chosen approach has been the parallel application of two methodologies to answer the question of the technological pathways and feasibility to achieve the 2-degree target for Europe: (1) the ADAM Hybrid Model System (ADAM-HMS), and (2) the POLES model. This approach enabled the results of the other parallel approach to be questioned and the technical solution to be verified. The outcome was that our work identified two feasible and economically viable technological pathways towards the 2-degree target.

The greatest methodological challenge was the integration of eight sectoral detailed bottom-up models and one macro-economic model into one interacting and integrated model system that is able to deliver consistent scenario results within a limited timeframe. We call this system the ADAM Hybrid Model System. The nine models are coupled via a web interface, which currently has to be applied by a central (human) operator. The interface is called Virtual Model Server (VMS). Each model result is delivered in a structured way to the VMS, is then processed and forwarded again in a structured way to the subsequent client models of the VMS. The VMS handles the data exchange in any direction i.e. from top-down to bottom-up, vice versa or in between the bottom-up models. To our knowledge this is the first time that such a hybrid system was successfully made operational for climate policy analysis.

The main requirements for improvements of the methodology are the automation of the VMS and having the system accessible in a decentralised manner via a web-interface instead of having a repository to deliver and receive the data to and from the operator. Further, the number of iterations that have been made in ADAM for generating the results should be increased, as the convergence achieved in particular for the CO_2 certificate prices could and should still be improved.

15.2 Conclusions from the bottom-up analyses

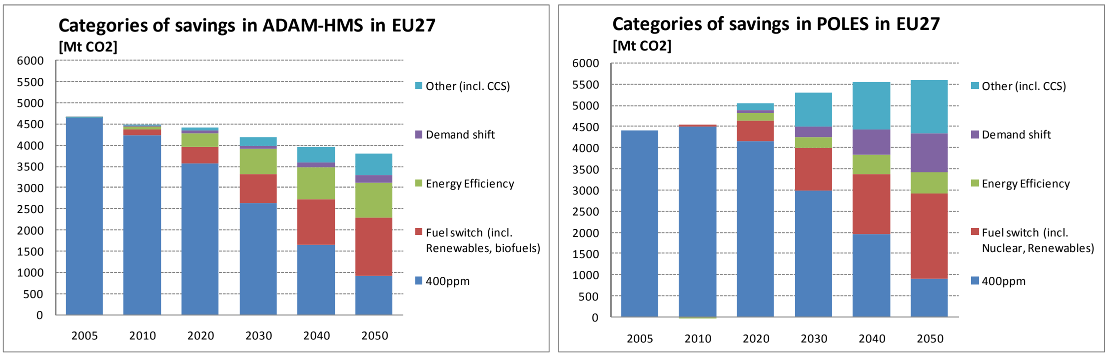
In the details of how and when, the two bottom-up analyses with the ADAM-HMS and the POLES model provide mostly consistent, but also partially divergent answers. Common to both approaches is the underlying pre-requisite of stringent policies and support to be able to meet the targets set by the European Commission.

In the ADAM-HMS, climate change mitigation concentrates on fostering a broad portfolio of renewable energies (including geo thermal and solar thermal) and efficiency technologies and practice (e.g. fuel efficiency standards of cars, insulation of buildings, top runner approach to electric appliances, energy service management systems), while, in POLES, energy-efficiency plays a smaller role and more weight is given to the use of biomass (including imports from outside of Europe) and to carbon capture and storage technologies.

Hence, the outcome of the ADAM-HMS is based on the findings that large energy and material efficiency options are available at a profitable level or low cost (partly used already in the Reference Scenario) and that large renewable energy potentials (both thermal and for electricity generation) can be tapped by adequate promotion measures which in turn reduce their costs by learning and economy of scale effects. The ADAM-HMS is mainly based on technologies and practices which are already present in the market place even though techno-economic progress is assumed. New energy- and material-efficient technologies as well as renewable energy technologies that might enter the market in the next decades are not a pre-requisite of the outcome, but would ease its realisation. Indeed, the literature is optimistic about the speed of market penetration of energy-efficiency and renewable energies.

Energy-efficiency is increased in the POLES model also, but to a lower extent and starting later and from a less efficient Reference Scenario. Fossil fuels in the end use sectors are displaced by biomass and electricity (also in cars and heat pumps) which is produced by nuclear energy, biomass, other renewables and fossil primary energy. CO_2-emissions from such fossil energy use are assumed to be captured and stored in aquifers.

The difference between the two proposed pathways of the ADAM-HMS and POLES are well illustrated by their contributions of emission cuts (Figure 15-1).



Source: ADAM-HMS and POLES

Figure 15-1: Comparison of categories of CO_2 savings in EU27 in ADAM-HMS (left) and POLES (right), 2000 to 2050, 400 ppm variant of the 2°C Scenario

The reasons for divergence between the two model systems must be looked for in the different expectations of how barriers to implement technologies can be overcome. Such barriers could be technological, economic or acceptance barriers, which require different and sector specific approaches. Thus the results of the two analyses can be interpreted as two possible storylines on how to reach the 2°C target which emphasise different, alternative mitigation options and related policies.

The baseline for both storylines is that carbon, or GHG emissions, have to be given a price, either in the form of an ETS or a greenhouse gas tax. However, such a policy on its own does not seem to be sufficient since (1) the price signals of an ETS in the first decades would be far too low to stimulate sufficient policy support for new technologies and sufficient behavioural change to implement sectoral policies. (2) Pricing systems are intended to affect markets, but markets in general apply a short-term perspective, looking at short-term rates of return and short-term break-even points, while the system transitions necessary for climate policy require a long-term perspective and can only be implemented over a long time horizon. Thus putting a price on greenhouse gases has to be accompanied by sectoral policies that give a powerful stimulus to new technologies and behavioural change from now until 2050.

The first storyline relates to the results of the ADAM-HMS. It concludes that the 2°C-Scenario for Europe can be achieved by: (1) immediate action investing in: (2) energy efficiency, (3) renewables, and (4) material efficiency. In case of partial failure to deliver or in case of delays, the second storyline from POLES could be followed, which argues that Europe can achieve the 2°C Scenario by (1) increased electrification, (2) high use of biomass (also from imports), and (3) substantial use of carbon capture and storage technologies (CCS).

To maintain the most economic options Europe would have to invest in R&D and large scale demonstration sites to further develop renewable technologies such as geothermal and wave energy and the CCS technology. Lastly, it should be mentioned that CCS constitutes only a transition technology because CO_2 storage capacities are finite and limit CCS in the long run.

15.3 Economic impact of mitigation in Europe

The basic conclusion from an economic point of view is that mitigation measures needed to meet the 2-degree target of the EU will not fundamentally alter Europe's economic development path. Some European regions will actually be better off with mitigation than without mitigation. A loss of GDP in EU27 of -1.7% and -2.7% in the 450 ppm and 400 ppm variants of the 2°C Scenario respectively at the end of the period in 2050, is acceptable considering that the financial crisis caused losses of GDP of -4% to -6% in the EU27 within less than 2 years, while the impact of mitigation remains less than half of this over a period of 40 years.

The impact on employment remains even more limited than on GDP. It is projected to be between +0.2%, i.e. mitigation fosters employment growth, and -0.3% of employment change until 2050 for the different regions of the EU. However, the sectors display considerable variation. Agriculture and industry gain employment because of the increased use of biomass and the mitigation investment into all kinds of machinery and electric appliances. The energy sector and other market services loose in employment: energy because of the reduced demand for energy and the services sector because of the price increase of services induced by the mitigation investment of the service sectors. It should be noticed that the service sectors face significantly higher price increases due to mitigation investment than the manufacturing sectors.

It should be pointed out that there are arguments that our results for the impact of the 2°C Scenario would be at the lower bound of possible changes of GDP. In particular model limitations may have led to double counting of avoided investment in the energy sector, so investment could be higher than projected here. A laissez-faire approach of government in response to the deterioration of its tax base related to fuel taxes rather than assuming revenue neutrality as in the current analysis (i.e. just accepting the reduction in revenues, leading to a reduction in deadweight losses from taxation) provide the arguments for the potential to develop economic scenarios in which mitigation might even generate a positive economic impact.

Comparing the cumulative amount of mitigation investment and savings of fossil energy imports it can be observed that before 2040 the cumulative mitigation investments are significantly higher, but this is turned around by 2050 when the cumulative savings of energy imports become higher than the mitigation investment. This trend should continue after 2050 and in this sense, mitigation measures represent a pre-investment into a profitable future which constitutes a strong argument for mitigation in Europe, as it contributes to both the two major objectives of the EU: winning the battle against climate change and securing Europe's energy supply.

15.4 Impact of the economic crisis on climate policy

The collapse of the global investment banks, with the consequent reduction in lending, instability of prices and falls in investment and trade, has led to reductions in industrial output, personal incomes, household expenditures, and hence in energy use and in greenhouse gas emissions. Since there is a data lag in the reporting of emissions, it is not yet clear how large the reduction will be, but it is likely to undermine earlier scenarios of continuous increases in emissions assumed in IPCC reports and other scenarios.

The long-term effect will depend on the length and depth of the global recession. During the Great Depression, from 1929-1934, global CO_2 emissions fell by 25%, but in the current crisis, which is expected to last at least until 2012, the energy system is substantially different, with coal use largely confined to electricity generation, and transportation a much larger share of overall energy demand. Both sources of demand for fossil fuels are likely to be more responsive to the fall in demand than in the Great Depression, but the industrial use of coal, which collapsed in the US 1929 to 1934, is much less important now. It is not yet clear how much CO_2 emissions will fall over the next year or so. Much depends on the responses of developing country governments to the crisis. If they take the opportunity to modernise or replace their polluting coal-fired electricity plants, switching to gas and renewables, then the emissions may fall rapidly.

Our macro-economic analysis of the current crisis uses a global energy-environment-economy model (E3MG) to assess these effects and finds that the long-term effect of the crisis is to reduce CO_2 emissions by some 10% below a trend baseline by 2020. However, the recession is just beginning and it is far from clear how governments will react in their policies towards the energy sector, and whether the old coal-burning plant will be retired never to return.

The sectoral analysis of the potential impacts of the economic crisis concluded that it will reduce the GHG emissions in the short-term and under a scenario of a permanent loss of GDP of -10% also in the long-term. The sectors reducing GHG emissions most due to the crisis would be industry and transport, where reductions in GHG emissions of the same order of magnitude as GDP are estimated.

In some cases, the crisis itself as well as the economic stimulus programmes will contribute to permanent reductions of GHG emissions by accelerating retirement of vehicles or facilities when their capacity is not needed anymore due to the crisis as well as by funding the renewal of vehicle fleets.

However, for the 2-degree scenarios there is also the major risk that lack of funding due to the crisis (e.g. because of reduced government budget) and increased risk averseness of investors or households will hamper the implementation of measures required to achieve the GHG emission reductions. This means, if policy does not put particular emphasis on mitigation policy the “conventional” way of handling the crisis will significantly reduce the chance that such 2-degree scenarios can be achieved. Therefore, **policy has to aim for policy programmes that integrate mitigating the crisis and mitigating climate change.**

One option to link climate mitigation policy and crisis management would be to follow the idea of the “Green New Deal”, which is to always link the economic stimulus with the requirement to introduce green technologies and GHG lean processes.

15.5 Policy suggestions

From the bottom-up analysis of climate change mitigation options in Europe we recommend the pursuit of the following strategy and principles to achieve the ambitious goal of the 2°C stabilization target. It is emphasised that these items are not optional, but it is a pre-requisite to take up all of them in order to maintain a coherent set and to assure success.

- Set the correct economic incentives : Assign carbon (or GHGs) a price as this translates the environmental constraints into a market signal.
- Set the necessary boundary conditions: level the playing field by implementing a coherent set of policy measures to overcome barriers and to guide (economic) incentives and to provide certainty for investors.
- New technologies play an important role in achieving the goals of ambitious climate policy economically. Thus considerable investments for public and private R&D are required for efficiency technologies, new renewables and, to limited extent, also CCS.
- Take immediate action since each year lost before shifting the transition pathway towards a low carbon society mean that even stronger action must be taken in the subsequent years.

Ultimately the goal of these policy strategies should be market transformation, i.e. enabling a take-up of low carbon technologies by the markets.

Coherent set of policy measures

There is a wide set of policy measures available that has been developed by the community and that has been explored in various countries (see various publications from the IEA, Fraunhofer ISI, and others). This includes codes and standards including mandatory energy performance standards (MEPS), financial instruments such as preferential loans and others, information instruments such as labels and public awareness campaigns, and professional training in various sectors (construction, energy conversion and use, financial, public administration). Ultimately limited time frame subsidy schemes that could be financed by a carbon levy might be necessary to achieve underlying ambitious assumptions. The optimal choice of these instruments depends on the situation of the countries considered and on the existing obstacles in individual sectors and target groups.

It is crucial to understand that not one or some few policy measures should be implemented, but a bundle of policy measures to address multiple barriers and the challenge which is multi-dimensional. Such a bundle should form a coherent set where individual measures are related to each other. The following paragraphs provide the concept of such a policy bundle, which is detailed in sections 5 to 11 of this report.

Residential and service sector

Policy instruments are structured according to the specifics of the energy use in the residential and the service sector: buildings, building technologies such as ventilation and cooling and appliances in households and offices. As mentioned above a pre-requisite of these sector-specific measures is an adequate economic framework (i.e. carbon pricing).

Whereas in the case of new buildings the adequate policy instrument is quite straightforward (codes and standards combined with labels and professional training), implementation of energy efficiency renewable energies in existing buildings poses several unique challenges. Policy measures in this sector include:

- Address the principal-agent problems between builders and investors and between building owners and tenants.
- Energy audits to point out inefficiencies and to provide technical and financial information to investors and building owners about what actions can be taken to reduce their energy bills and at what cost.
- Information campaigns to foster public awareness and local information centres that provide advice to households and small-to-medium size enterprises.
- Professional training for architects, planners and craftsmen.
- Financial instruments including preferential loans, contracting and ultimately subsidies to address the barrier of higher initial investment costs. This requires the participation of private banks.

Regarding electrical appliances, the following policy measures have been assumed in the projections and are subject to our policy recommendations:

- Establish regularly updated minimum energy performance standards (MEPS) to ensure phase out of inefficient equipment and products.
- Design labels (comparison labels and endorsement labels) to inform consumers of the costs and benefits of the most and least efficient appliances on the market.

- Encourage well monitored voluntary or negotiated agreements with appliance manufacturers to enhance the overall efficiency of products.
- Support research and development, including encouraging manufacturers to integrate energy efficiency considerations into the early stages of product design.

Apart from the instruments stated above which are valid for both residential and commercial buildings, the following instruments are specifically targeting the buildings of the service sector including the public sector:

- Encourage integral planning and commissioning of new buildings to establish energy-efficient operation.
- Stimulate continuous monitoring and optimisation of building technology operation to avoid energy consumption without use.
- Promote the use of renewable energies including ambient air and ground sources in the context of (free) cooling and managing heating and cooling needs.

To conclude: A very active energy efficiency and renewable energy policy is needed by all the European countries regarding buildings in the service sector, as the re-investment cycle of buildings and building technologies is quite long (20 to more than 60 years). It must be stressed that the intensity of policy measures has to be augmented considerably compared to past and present activities in order to be able to achieve the improvements and emission reductions described in this section.

Industry and material efficiency

The emission and energy demand reductions of the industrial sector in the 2°C Scenario are enormous and will need strong policies to be achieved. Policies on material efficiency have still not received the necessary attention as a climate change policy element reducing the industrial energy demand by some 20 %. Energy efficiency has to improve a lot faster than economic growth by applying the relevant policies. This constitutes a major challenge in the light of past developments.

Policy instruments are differentiated between large energy-intensive companies that may participate in the EU emission trading system (ETS), and other, small and medium sized enterprises. For companies under the ETS regime increasing certificate prices will render mitigation options profitable to a large extent.

For others the ETS provides no incentives due to the non-economic nature of the barriers. Often, cost-effective options are neglected by company decision makers, because they are not in their core interest. Here additional policies are required, such as a set of policies to exploit the frequently cost-effective saving potentials due to optimisation of motor and lighting systems as well as steam and heat supply systems:

- Instruments like the energy efficiency networks, energy efficiency funds and energy management systems as well as wider use of contracting are very effective with respect to reducing transaction costs, to raise and direct awareness of companies and to overcome financial bottlenecks.
- Efficiency potentials of mass produced investments goods such as electrical motors, pumps, fans, compressors can most efficiently be realised by standards and labelling. The minimum energy performance standards (MEPS) for electric motors are one example.
- In particular, to boost industrial process innovations and to improve energy efficiency in the long-term, R&D spending need to increase significantly. A time frame of 10-20 years for the development of new marketable production processes together with a high risk of failure is not unusual. In order to undertake these long-term investments companies mostly need public R&D support.
- Besides the strong energy efficiency improvements, a comprehensive material efficiency strategy plays a key role in reducing the demand for emission intensive products, also by substituting certain products with low carbon products or materials. The policy instruments needed are quite similar to those in improving energy efficient solutions (e.g. technical standards for recycling, professional training, information campaigns, financial incentives, learning networks, and R&D).

Transportation

In the past, the transport sector has been excluded from the international greenhouse gas emission agreements. Thus its emissions have continued to increase strongly and it is a growing obstacle to climate policy. Recent studies have shown the large GHG reduction potentials in the transport sector. This is confirmed by our analysis. However, including transport in the EU-ETS is not sufficient to transform it into a low carbon and climate-friendly activity. Thus besides including transport in the EU-ETS, a package of transport-focussed policy measures has to be implemented, including regulation, taxation, R&D support and information campaigns. One main issue is that policy-makers have to make it very clear to decision-makers in companies and households that climate protection policies in the transport sector are not a short-term policy fashion, but will be pursued forcefully and over the medium and long term.

In this summary only the core policy measures to be taken in the transport sector should be spelled out:

- Energy efficiency improvements: even with current combustion engine technology large efficiency gains of vehicles can be achieved. Setting CO_2 emission limits for cars, light duty vehicles and heavy trucks should be the key priority in the short- to medium-term.
- Fuel switch and new technologies: in the medium to long-term this will play the largest role. The development of electric vehicles and - assuming that the battery capacity problem can not be solved – hydrogen fuel cell vehicles should be fostered by R&D , feebates and similar market introduction programmes. This holds for cars and light duty vehicles.
- Efficient logistics and demand shift: the EU has successfully implemented measures to improve the competitiveness of railways. Together with logistics improvements for road, ship and rail this should be continued to shift more long-distance freight transport towards rail and to reduce vehicle-km by improved load factors and reduced empty trips.
- Biofuels: since for heavy trucks and air transport technical options are limited and/or require very long time scales the binding use of biofuels (full plants/2nd generation and algae/3rd generation) should be introduced by setting quotas of blended fuel.

The European power conversion sector including renewable energy sources

A number of important changes are required in the conversion sector to achieve the stringent mitigation targets explored in this analysis. These include phase-out of CO_2 emitting fossil generation, a continued deployment of nuclear energy and large-scale deployment of renewables. To achieve the required changes, we recommend the application of the following policy measures in the conversion sector:

- **address concerns** regarding waste disposal, risk of accidents and nuclear proliferation with regard to the use of **nuclear energy** and thus ensure sufficient public support for this technology.
- set **high and stable CO_2 prices** which are likely to be achieved by CO_2 taxes or cap and trade systems to bring forward the phase-out of CO_2 emitting fossil generation.
- support open and efficient **markets for international electricity trading**. Thus, additional flexibility where countries have lower access to power plants that can be operated more or less on demand, such as hydroelectric power plants with pump storage, can be provided. Electricity trading also enables the exploitation of the renewable potentials in those regions where they are highest.

Increasing the share of renewable energy sources in the electricity mix was identified as a crucial factor within the conversion sector which could make a substantial contribution to mitigating climate change. However, the sole application of the European emission trading scheme does not provide sufficient incentives to make most renewables options competitive with other conversion technologies at least during the next two decades. The enhanced use of renewable energy sources requires the implementation of various additional policy measures including:

- the application of **sectoral policy measures** adapted to the specific requirements of renewables, such as feed-in tariff systems. These policies should be technology-specific and provide sufficient investment security. The policy measures should be based on a financial support level which is designed such that renewables projects become profitable without overcompensating investors.
- Implement **research and development (R&D)** policies for emerging technologies. Owing to the fact that the policy assumptions in the 2° Scenario reflect very ambitious climate targets, this would be likely to happen.
- Consider further alternatives, such as **importing green electricity** from outside the EU, to a limited extent.

Forestry

Improved forest management in all European countries would increase the potential for wood fuels in the form of a CO_2 neutral fuel. New technologies and policy efforts would enlarge the potential. Such efforts include full-service contracts to small private forest owners, support to ownership co-operations, support in making management plans, awareness campaigns about the environmental benefits of biomass harvest, and stimulation of integration of different types of measures with biomass removal (nature conservation measures, fuel reduction against forest fires).

Cross-cutting and long-term policy aspects

Energy subsidies of the fossil fuel industry are still substantial – whether direct or indirect - in many European countries. Phasing out these subsidies by realigning fuel prices would stimulate both supply- and demand-side energy efficiency investments.

Foster the system transition of urban structures since (1) more than 50 % of persons live in urban areas and their share will grow; (2) the integrated development of city structures and transport infrastructures reduce the need for motorized transport and paves the way for new forms of mobility (e.g. car- and bike-sharing, electric city and delivery vehicles, barrier-free, multi-modal transport); (3) the creative potential of urban areas attracts qualified and young/innovative groups of people open to transitions of urban structures.

Multi-stakeholder collaborative efforts that facilitate technology diffusion to emerging market economies and developing countries where commercial market opportunities exist should be considered as a way to reduce costs by additional economies of scale. Also the opposite should be explored given very large mass consumer markets in Asia or low labour cost to produce labour–intensive efficiency goods (e.g. heat exchangers). Such initiatives should focus on increasing the scope of the technology transfer process to include small and medium entrepreneurs, large multi-national energy companies, and other stakeholders such as research institutions and financial institutions.

The measures suggested in this report are not science fiction. However, they need strong support by todays policy-makers, who have the most difficult task. They will have to promote such policies even though visible climate impacts are limited, yet, and knowledge of the possible impacts is limited as well. Future generations of policy-makers - and private decision-makers - will have an easier task, as climate change will be more visible. On the other hand, for future policy-makers it would be too late to mitigate climate change, if today's policy-makers do not start to implement our suggested mitigation measures.

16 Annexes

Authors: Nicki Helfrich, Wolfgang Schade, Laura Quandt

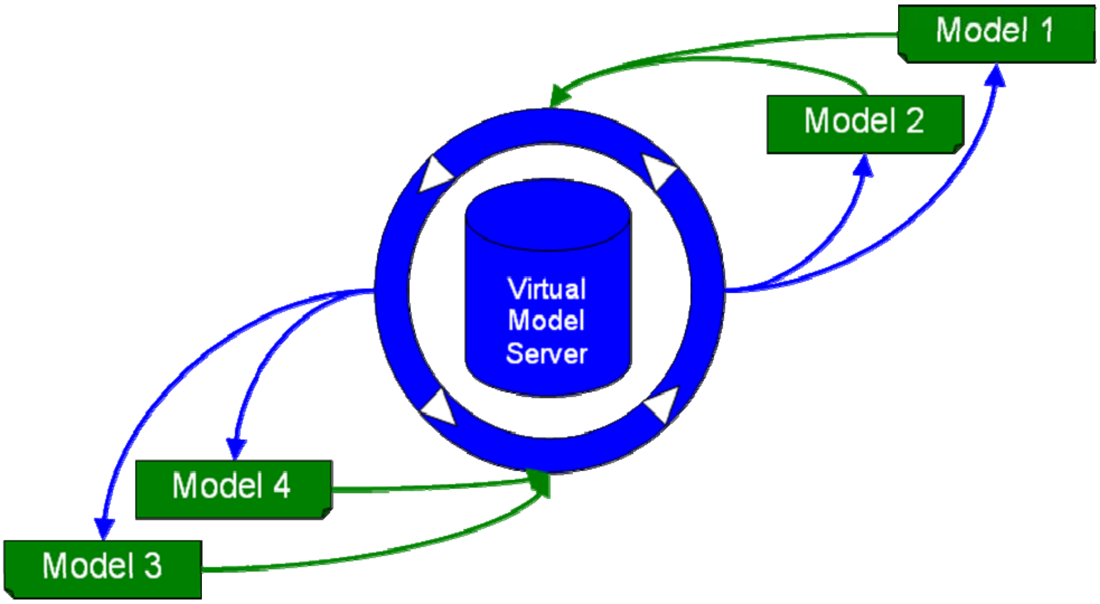
16.1 Details of the Virtual Model Server (VMS)

Managing and automating the exchange of data between the models was a major challenge within the ADAM M1 project, since 7 to 9 models covering different fields of specialisation were exchanging data. This exchange had to be done repeatedly, resulting in iterations of model simulations in order to achieve convergence, harmonise the model's assumptions and generate consistent results. Manual transformation of the repeatedly exchanged huge amounts of data would have been highly repetitious work, which naturally is extremely error-prone and time consuming.

Therefore, a configurable software – the Virtual Model Server (VMS) – was developed for the data exchange and used as described in the two subsequent sections. The full documentation is provided in [Helfrich/Reusch 2009].

16.1.1 Virtual Model Server – automated data exchange

The virtual model server – VMS – was developed by Nicki Helfrich and Jan Reusch of Fraunhofer ISI in order to automate complex data transformations when passing data from one model to another and to manage sequences of transformation steps for running models in series, each model using the output of it predecessor as input. With this software the iteration of model simulations is also possible, i.e. a sequence of simulations in which the starting model eventually receives data from another model calculated based on the first models results. This is depicted as an abstract example in Figure 16-1. Here, models 1 and 2 start the iteration and send their resulting data to the VMS. The server transforms the data into the format needed by models 3 and 4, each receiving different input formats and different subsets of the data provided by models 1 and 2. Then, models 3 and 4 can run their simulations and send their results to the VMS, for the compilation of input for the next models in the sequence, in our example models 1 and 2, which started the sequence. These two can then calculate again and continue the simulation loop.



Source: own illustration

Figure 16-1: Virtual Model Server – abstract data flow

16.1.1.1 Technical details

The VMS was developed purely in *Java* as a web application for the *Tomcat Application Server* with a *MySQL database* as data storage backend, all following the open source philosophy. It builds on a variety of open source libraries for various functionalities. Most importantly, it uses *Hibernate* along with *Spring* for persistent data.

16.1.1.2 Design philosophy

The development of the software was driven by the idea of creating a highly configurable tool, which should not be specific to certain interfacing and transformation tasks. This design enables the adoption of model output transformation definitions without changing neither the source code of the source model nor of the target model. All transformations are defined using an XML subset specifically developed for this purpose. With this design philosophy, we managed to create a highly reusable tool as it is possible to integrate new models into the data exchange. Thus the VMS enormously facilitates the data transformation tasks when integrating two or more models into an interacting hybrid model system.

16.1.1.3 Functionality

For defining the transformations, three major parts are necessary. First, for each model all relevant input attributes have to be defined. This is done in the *model definition*. Second, the data transformations have to be defined on a variable by variable base, describing for each input variable of the subsequent model in the iteration sequence how it is composed of the output variables of the preceding models. This is the *transformation definition*. And third, the sequence of transformations has to be defined in the *sequence definition*. The latter is important when the sequence of running the models plays a role for generating results, which is most often the case.

Model definition

For each model, a definition file is compiled containing the following information:

- Variables and the dimensions they are defined on
- Dimensions e.g. indexes for countries or economic sectors
- Timeframe and time intervals
- File Format

An example is given in Source:VMS, Fraunhofer-ISI

Figure 16-2It shows an extraction of the definition of the ASTRA model for the VMS. The root knot (or object) is *model*, containing the *name*, *timescope*, *dimensions*, *variables* and *fileFormats* knot. Within *dimensions*, the two dimensions EUCoun and IOSector are defined with their according elements. These are then referred to within the knot *variables*, containing definitions for the two variables MAC_emp_Employment_per_Country and MAC_emp_Employment_Sectoral_incl_Part_Time. The first variable is only defined based on the EUCoun dimension (EU27+2 countries), the second based on both EUCoun and IOSector (25 economic sectors). And eventually the last knot *fileFormats* includes references to XML files defining the data structure of the ASTRA model, in this case in- and output data structure being the same.

```xml
<model>
  <name>ASTRA</name>
  <timescope>
    <startyear>1990</startyear>
    <endyear>2050</endyear>
    <timesteps>1</timesteps>
  </timescope>
  <dimensions>
    <dimension name="EUCoun">
      <element_list>
        AUT, BLX, DNK, ESP, FIN, FRA, GBR, GER, GRC, IRL, ITA, NLD, PRT,
        SWE, BLG, CHE, CYP, CZE, EST, HUN, LAT, LTU, MLT, NOR, POL, ROM,
        SLO, SVK
      </element_list>
    </dimension>
    <dimension name="IOSector">
      <element_list>
         Agriculture, Energy, Metals, Minerals, Chemicals,
         Metal_Products, Industrial_Machines, Computers, Electronics,
         Vehicles, Food, Textiles, Paper, Plastics, Other_Manufacturing,
         Construction, Trade, Catering, Transport_Inland,
         Transport_Air_Maritime, Transport_Auxiliary, Communication,
         Banking, Other_Market_Services, Non_Market_Services
      </element_list>
    </dimension>
  </dimensions>
  <variables>
    <variable name="MAC_emp_Employment_per_Country">
      <dimension_ref ref="EUCoun" />
    </variable>
    <variable name="MAC_emp_Employment_Sectoral_incl_Part_Time">
      <dimension_ref ref="EUCoun" />
      <dimension_ref ref="IOSector" />
    </variable>
  </variables>
  <fileFormats>
    <input file="Astra-output.xml" />
    <output file="Astra-output.xml" />
  </fileFormats>
</model>
```

Source: VMS, Fraunhofer-ISI

Figure 16-2: Model definition – XML example file

Transformation definition

The core functionality of the VMS is the ability to transform data in an automated way. Therefore, a definition language was developed in order to describe the transformations based on XML. VMS features the following operations:

- Basic arithmetic operations: addition, subtraction, multiplication, division.
- Dimension mapping, i.e. the definition of how one dimension of model A refers to a related but differently named or aggregated dimension of model B. This definition is described as a matrix stored in an MS Excel spreadsheet.
- MAC_emp_Employment_Sectoral_incl_Part_Time, defined on EUCoun and IOSector to a one-dimensional variable defined on EUCoun by adding up all elements of IOSector.

- Splitting dimensions, i.e. the inverse operation of the aggregation, producing e.g. a two-dimensional variable based on a one-dimensional variable with fixed split factors for the elements of the new dimension.
- Intermediate variables for calculating various steps with the VMS, where the output of one calculation is the input for the next calculation.
- Index calculation, i.e. the ability to calculate an index on a given base year of a variable.
- Temporal interpolation, i.e. filling years not covered by the output of model A but needed in the subsequent model B. This is done as linear interpolation.

```
<modelTransformation>
  <model ref="EuroMM" />
  <variables>
    <add variable="DSELHT">
      <summand>
        <var model="cepe" variable="EE_SERV-h">
          <dimensions>
            <map from="CountryCode" to="Region" mapping="to_euromm.xls"
              factor="1" />
            <join from="Fuels" fixedElement="Electricity" />
          </dimensions>
        </var>
      </summand>
      <summand>
        <var model="cepe" variable="EE_SERV-h">
          <dimensions>
            <map from="CountryCode" to="Region" mapping="to_euromm.xls"
              factor="1" />
            <join from="Fuels" fixedElement="El.HP" />
          </dimensions>
        </var>
      </summand>
    </add>
    <add variable="DTGSL">
      <summand>
        <var model="ASTRA" variable="ENV_FC_Gasoline_Mtoe">
          <dimensions>
            <map from="EUCoun" to="Region" mapping="to_euromm.xls"
              factor="41.868" />
          </dimensions>
        </var>
      </summand>
    </add>
  </variables>
</modelTransformation>
```

Figure 16-3: Transformation definition – XML example file

The transformations are organized by target model, i.e. for each input data set generated for a model, one transformation file is set up, containing all definitions of how to compile that input based on the output of the preceding models within the sequence. An example is given in Figure 16-3, including an extraction of the transformations defining the calculation of the input for the model EuroMM. The example shows how an addition works. The first case showing how two elements of the dimension *Fuels* are added up. The variable *DSELHT* is calculated as the sum of dimension *Electricity* and of *El.HP* of the variable EE_SERV-h. The second case shows a transformation from ASTRA variable *ENV_FC_Gasoline_Mtoe* to the EuroMM variable *DTGSL* based on a dimension mapping from *EUCoun* (ASTRA index of countries) to *Region* (EuroMM index of countries). This mapping is shown in Table 16-1. There, the first column contains the elements of the dimension EUCoun, the first row contains the elements of the EuroMM dimension Region. Both dimensions refer to the spatial resolution of the model, but the definitions are not equal. Therefore, this mapping is needed. It defines, e.g., that the code SCA of EuroMM will be calculated as the sum of DNK and FIN of the ASTRA model. With a factor <1 a split of one dimension to various dimensions can be defined. This mapping is applied during the transformation of the ASTRA to the EuroMM variable due to the *map* knot within the *dimensions* knot in the example.

Table 16-1: Dimension mapping example - from ASTRA EUCoun to EuroMM Region

to from	AUT	BAL	BELU	BURO	CZSL	FR	GBI	GER	GRC	HUSLE	IBE	ITA	MC	NDL	NOR	POL	SCA	SWI	ROW
AUT	1																		
BLG				1															
BLX			1																
CHE																		1	
CYP													1						
CZE					1														
DNK																	1		
ESP											1								
EST		1																	
FIN																	1		
FRA						1													
GBR							1												
GER								1											
GRC									1										
HUN										1									
IRL							1												
ITA												1							
LAT		1																	
LTU		1																	
MLT													1						
NLD														1					
NOR															1				
POL																1			
PRT											1								
ROM				1															
SLO										1									
SVK					1														
SWE																	1		

Source: VMS, Fraunhofer-ISI

For all further functionality, similar XML definitions were developed. It would be to lengthy to describe the whole syntax in detail in the scope of this document. Therefore, we refer to the complete documentation of the VMS [Helfrich/Reusch 2009].

<u>Sequence definition</u>

Eventually, the order in which

- the individual models calculate results,

- deliver the results to the VMS,
- the VMS transfers these results and hands them over to the next model

has to be defined. This is done in the sequence definition, another XML file. A reduced example is shown in Figure 16-4. It defines that in step 0, the initialization, the models ASTRA, Cepe and ISIndustry calculate initial results. Step 1 then consists of the transformations according to the file *mappings/to_euromm.xml* which result in one input file for EuroMM. The sequence then continues with further *step* elements.

```
<scenarioTrackerDefinitions>
  <track>
    <iterations>1</iterations>
    <step number="0">
      <subStep>
        <model ref="ASTRA" />
      </subStep>
      <subStep>
        <model ref="cepe" />
      </subStep>
      <subStep>
        <model ref="ISIndustry" />
      </subStep>
    </step>
    <step number="1">
      <subStep>
        <model ref="EuroMM" />
        <transformation file="mappings/to_euromm.xml">
          <requiredModel ref="ASTRA" />
          <requiredModel ref="cepe" />
          <requiredModel ref="ISIndustry" />
        </transformation>
      </subStep>
    </step>
  </track>
</scenarioTrackerDefinitions>
```

Figure 16-4: Sequence definition – XML example file

16.1.2 Data flow between models

Using the Virtual Model Server described in the previous section, a large amount of data was exchanged between the various models collaborating during the project. The details about which data was exchanged in what sequence are described in this section. Table 16-2 gives a high level overview of which data is exchanged by the individual models. As can be seen there, PowerACE delivers data to EuroMM and ASTRA. ISIndustry provides data to PowerACE, EuroMM and ASTRA. CEPE models hand over data to PowerACE, EuroMM and ASTRA. From EuroMM, data is transferred to PowerACE, CEPE models and ASTRA. From ASTRA, data is carried over to PowerACE, ISIndustry, CEPE models and EuroMM. Most data is provided as yearly figures, with the exceptions of EuroMM data, which is provided (required) as 5 year aggregates or data for every 5th year. The details of what data is transferred between the models for each direct bilateral link are summarized in Table 16-3.

Table 16-2: Data flow between models – high level overview

to / from	Power ACE	ISIndustry	CEPE models	EuroMM	ASTRA
Power ACE		✘	✘	✓	✓
ISIndustry	✓		✘	✓	✓
CEPE models	✓	✘		✓	✓
EuroMM	✓	✘	✓		✓
ASTRA	✓	✓	✓	✓	

Source: Own compilation, CEPE models: RESIDENT, SERVE, RESAppliance

The following list describes the implemented transfer of data for the ADAM-HMS that are handled by the VMS (Table 16-3 provides an overview):

- EuroMM provides the CEPE models with prices for electricity. These are provided per country both as separate electricity prices for industry as well as for households. Since the two models use different country groups, a mapping from the countries of EuroMM to the countries of the CEPE models had to be defined. Further, the currency had to be converted from US$ 2000 to Euro 2005.
- ASTRA delivers Value added and Employment to the CEPE models. The data is disaggregated per country and per sector. Both countries and sectors are defined differently in the two models, therefore, mappings for both dimensions were developed. Both variables were delivered to CEPE as index variables with the value of 2004 as a base year.
- ISIndustry supplies PowerACE with data on the electricity consumption of the industry per country. Due to differing country definitions, a mapping was developed, and the unit was converted from Mtoe to GWh.
- The CEPE models give data on the electricity demand of the service sector as well as the residential sector to the PowerACE model. The unit is converted from PJ to GWh and the countries were mapped to bridge the differing country groups.
- From ASTRA, data on the electricity demand of the transport sector is handed over to PowerACE. This is differentiated by countries. These differ in the way they are grouped, wherefore a specific mapping was developed. The unit was converted from Mtoe to GWh.
- PowerACE is provided with the amount of generated electricity by EuroMM. A specific country mapping was elaborated. The data coming from EuroMM is disaggregated by electricity producing technology, but since this information is not needed by PowerACE, all

quantities were aggregated into one figure per country for PowerACE. The unit was converted from PJ to GWh.

- ASTRA receives data on Investments into renewable energy technologies from PowerACE distinguished by country and by technology. Both country and technology group definitions differ in the two models, wherefore a mapping for both dimensions was developed. Additionally, the currency was converted from constant Euro 2005 to constant Euro 1995.
- ASTRA is further supplied by ISIndustry with data on energy consumption of the industry, distinguished by country, industry sector and energy type, as well as investment figures for CCS, electrical appliances and for general equipment. The investments are disaggregated to specific countries, with the general investment figures additionally disaggregated by industry sector. For the sectoral aggregations, a mapping was needed due to differing sectoral aggregations in the two models. While the energy figures are kept in Mtoe figures, the investments were converted from constant Euro 2000 to constant Euro 1995.
- Furthermore, ASTRA receives data from CEPE on investments into air conditioning, efficiency improvements and fuel substitution, on expenditures for energy and energy demand, both given fuels and for electricity. All data is provided by country, for which a mapping to the ASTRA countries was developed. Additionally, the investment figures are also disaggregated by sectors, which were mapped to the ASTRA sectors. The monetary figures were converted from Euro 2005 to Euro1995 and energy variables from PJ to Mtoe.
- Also, ASTRA receives data from EuroMM on energy costs, energy demand, expenditures for energy, CO_2 certificate prices, energy imports and on investments. All data is provided per country. A mapping from EuroMM countries to ASTRA countries was developed. Energy costs are provided by energy type in a more disaggregated way than needed by ASTRA, therefore average costs were calculated, weighted with the energy demand, and aggregated to energy use groups as needed by ASTRA. Energy import data is provided differentiated by origin and destination country, but needed only by destination country. Therefore an aggregation was defined, aggregating all imports into one country into one figure. The investment figures which are provided by EuroMM differentiated by technology were aggregated into one figure by country. Investments and CO_2 certificate prices were converted from US$ 2000 to Euro 1995. For the energy values the relative change between scenarios was provided to ASTRA. All figures except investments were provided for each 5^{th} year. Therefore, the missing years were filled with interpolated data. The investment figures were provided as 5 year aggregates, therefore the values were evenly distributed among the five years represented by the EuroMM output value.

- EuroMM uses data from PowerACE, ISIndustry, the CEPE models and from ASTRA. PowerACE delivers capacity extensions in the renewable energy sector to EuroMM, by country and technology.
- ISIndustry provides EuroMM with data on the energy consumption of the industry for each energy type. The countries are mapped from ISIndustry country groups to EuroMM country groups, and the unit is converted from Mtoe to PJ. Only data for every 5th year is given to EuroMM.
- CEPE supplies EuroMM with data on the energy consumption of the service sector and the households. The data is disaggregated by country and energy type. The country definitions are mapped from CEPE to EuroMM countries. For each combination of usage area (service sector, household) and energy type, one variable is given to EuroMM.
- From ASTRA, EuroMM receives data on the consumption of transport fuels differentiated by fuel type and on the transport performance, differentiated by transport mode. The countries are mapped from ASTRA countries to EuroMM countries, and the energy figures are converted from Mtoe to PJ. The transport performance was only delivered initially and was not part of the iteration process, since the adoption of these numbers is not highly significant to the model results.
- Also, ASTRA data on gross value added was handed over to ISIndustry. The data is available disaggregated by country and by industry sector. Therefore, two mappings for these two dimensions were needed, transforming ASTRA to ISIndustry countries and sectors. The currency was converted from Euro1995 to Euro 2000.

Table 16-3: Data flow between models – details

Source Model	Target Model	Data exchanged	Source Dissagregation		Source Unit	Source temp. resol.	Target Dissagregation		Target Unit	Target temp. resol.
EuroMM	CEPE	Electricity prices	per country		2000$US M/PJ	yearly	per country		Euro 2005 / GJ	yearly
		for Housholds and Industry	per country		2000$US M/PJ	yearly	per country		Euro 2005 / GJ	yearly
ASTRA	CEPE	Value added	per country	per sector	Mio Euro 1995	yearly	per country	per sector	Index 2004	yearly
		Employment	per country	per sector	Persons	yearly	per country	per sector	Index 2004	yearly
ISIndustry	PowerACE	Electricity consumption of industry	per country		Mtoe	yearly	per country		GWh	yearly
CEPE	PowerACE	Electricity demand by Service and Residential Sector	per country		PJ	yearly	per country		GWh	yearly
ASTRA	PowerACE	Electricity demand of transport sector	per country		Mtoe	yearly	per country		GWh	yearly
EuroMM	PowerACE	Electricity generation	per country	Technology	PJ	each 5th year	per country		GWh	each 5th year
PowerACE	ASTRA	Additional Investments into renewable energy techchnologies	per country	per technology	Mio Euro 2005		per country	per technology	Mio Euro 1995	
ISIndustry	ASTRA	Energy consumption of Industry per energy type	per country	per sector	Mtoe	yearly	per country	per sector	Mtoe	yearly
		Investment into CCS	per country		Mio Euro 2000	yearly	per country		Mio Euro 1995	yearly
		Investment into electrical appliances	per country		Mio Euro 2000	yearly	per country		Mio Euro 1995	yearly
		General investment demand	per country	per sector	Mio Euro 2000	yearly	per country	per sector	Mio Euro 1995	yearly
CEPE	ASTRA	Investments into - Air conditioning - Efficiency improvements - Fuel substitution for Service Sector and Housholds	per country	per sector	Mio Euro 2005	yearly	per country	per sector	Mio Euro 1995	
		Expenditures for - Fuel - Electricity by Service Sector and by Housholds	per country		Mio Euro 2005	yearly	per country		Mio Euro 1995	
		Energy demand for - Fuel - Electricity by Service Sector and by Housholds	per country		PJ	yearly	per country		Mtoe	
EuroMM	ASTRA	Energy costs	per country	Energy type	2000$US M/PJ	each 5th year	per country	EnergyType_Sector	Factor - change	yearly
		Energy demand	per country	Energy type	PJ	each 5th year	per country	EnergyType_Sector	Factor - change	yearly
		Energy expenditures	per country	Energy type	2000$US	each 5th year	per country	EnergyType_Sector	Factor - change	yearly
		CO2 Certificate Prices	per country		2000$US	each 5th year	per country		Euro1995	yearly
		Energy imports into country	per country	Energy carriers	PJ	each 5th year	per country		Factor - change	yearly
		Investments	per country	per technology	2000$US M	5 year agg	per country		Mio Euro1995	yearly
PowerACE	EuroMM	Capacity extension in renewable energy sector	per country	per technology	MW	yearly	per country	per technology	MW	5 year agg
ISIndustry	EuroMM	Energy consumption of Industry per energy type	per country		Mtoe	yearly	per country		PJ	each 5th year
CEPE	EuroMM	Energy demand of - Service sector - Housholds disaggregated per energy type	per country		PJ	yearly	per country		PJ	each 5th year
ASTRA	EuroMM	Transport Fuel Consumption per Fuel Type	per country		Mtoe	yearly	per country		PJ	each 5th year
		Transport Performance (not iterated)	per country	per mode	pkm or tkm	yearly	per country		pkm or tkm	yearly
ASTRA	ISIndustry	Gross Value added	per country	per sector	Mio Euro 1995	yearly	per country	per sector	Mio Euro 2000	yearly

Source: own compilation, VMS, Fraunhofer-ISI

16.2 Detailed Results from the MATEFF model

More detailed data of the MATEFF model assumptions and results are presented here (see Chapter 5.2).

16.2.1 Assumptions of the Reference Scenario – 2000 to 2050

The results of this scenario reflect the trend to material efficiency and intra-industrial structural changes without any additional attempt to reduce the demand of energy-intensive materials.

Assumptions about the drivers of steel production in Europe

At present (and expected to remain that way in the future), Greece, Norway, and Switzerland only produce recycled steel using electricity, which means the crude steel production of these countries matches their electrical steel production (Table 16-4 and Table 16-5). In contrast, the Baltic States produce exclusively crude steel. Latvia is the leading steel manufacturer among the Baltic States. Portugal (at present), Slovenia (at present), Spain (from 2015) and Italy (from 2030) produce a very high share of electrical steel. The percentage of electrical steel in these countries averages more than 80 % of total steel production and their electrical steel production is projected to grow by 0.3 % per year.

Malta/Cyprus do not produce steel at all, neither oxygen steel nor electrical steel. Denmark does not produce any crude steel at present either. Denmark's oxygen steel plants were closed in 1980 and electrical steel ceased to be produced here in 2003. Ireland stopped producing crude steel in 2002 (oxygen steel before 1990 and electrical steel in 2002, see Table 16-4).

The per capita electrical steel production of many European countries (Austria, Belgium/-Luxembourg, Finland, France, Germany, the Netherlands, Sweden, United Kingdom, the Czech Republic, Hungary, Poland, Slovakia, Romania and Turkey) increases by an average of 0.6 % per year (see Table 16-5).

Assumptions about the drivers of aluminium production in Europe

Most other countries (Greece, Italy, the Netherlands, Poland, Slovakia, Slovenia, Sweden and Switzerland) maintain a constant level of aluminium production after 2020. The United Kingdom shows a constant level of primary aluminium production for the entire period.

Only Norway and Turkey feature increasing primary aluminium production throughout the period 2005 to 2050 due to the inexpensive electricity from hydropower in Norway and the high domestic demand in Turkey with new, efficient power stations. Over the same period, the primary aluminium production in Germany decreases by about 45 %.

Belgium/Luxembourg, Ireland and Cyprus/Malta do not have any *secondary aluminium production*. Belgium stopped producing secondary aluminium in 2005 and Switzerland in 2002. Based on the production of *secondary aluminium* in the year 2005, its development was estimated for

EU27 (+ Norway, Switzerland, Turkey). Again, the development of production between the estimated values for each decade is calculated as a linear increase or decrease.

The data concerning the secondary aluminium production of the Eastern European countries (the Baltic States, Slovakia, Slovenia and Turkey) are not specified (see Table 16-6:). It is estimated that Turkey will start producing secondary aluminium in 2020, which may be a rather conservative estimate.

Table 16-4: Estimated production of crude steel in tonnes per capita in EU27 + Norway, Switzerland and Turkey, Reference Scenario 2005 – 2050

Country or Country group	2005	2030	2050
Austria	0.86	0.60	0.50
Baltic States	0.24	0.20	0.20
Belgium/Luxembourg	5.72	5.50	4.95
Bulgaria	0.26	0.30	0.30
Czech Republic	0.61	0.50	0.45
Denmark	–	–	–
Finland	0.90	0.70	0.60
France	0.32	0.30	0.25
Germany	0.54	0.56	0.56
Greece	0.20	0.17	0.24
Hungary	0.20	0.20	0.20
Ireland	–	–	–
Italy	0.50	0.45	0.40
Malta/Cyprus	–	–	–
the Netherlands	0.42	0.40	0.40
Norway	0.15	0.15	0.15
Poland	0.22	0.30	0.27
Portugal	0.13	0.10	0.11
Romania	0.29	0.30	0.30
Slovakia	0.80	0.65	0.41
Slovenia	0.29	0.36	0.30
Spain	0.42	0.40	0.40
Sweden	0.63	0.55	0.50
Switzerland	0.14	0.18	0.20
United Kingdom	0.22	0.22	0.20
Turkey	0.29	0.50	0.45

Source: BSR Sustainability GmbH

Table 16-5: Estimated production of electrical steel in tonnes per capita in EU27 + Norway, Switzerland and Turkey, Reference Scenario 2005 – 2050

Country or Country group	2005	2030	2050
Austria	0.08	0.09	0.10
Baltic States	–	–	–
Belgium/Luxembourg	0.45	0.49	0.54
Bulgaria	0.10	0.14	0.19
Czech Republic	0.06	0.07	0.09
Denmark	–	–	–
Finland	0.27	0.30	0.35
France	0.12	0.13	0.15
Germany	0.17	0.20	0.23
Greece	0.20	0.22	0.24
Hungary	0.03	0.04	0.05
Ireland	–	–	–
Italy	0.30	0.36	0.42
Malta/Cyprus	–	–	–
Netherlands	0.01	0.01	0.01
Norway	0.15	0.15	0.15
Poland	0.09	0.11	0.14
Portugal	0.07	0.09	0.11
Romania	0.08	0.10	0.14
Slovakia	0.07	0.08	0.10
Slovenia	0.30	0.36	0.43
Spain	0.31	0.34	0.37
Sweden	0.20	0.21	0.23
Switzerland	0.14	0.18	0.20
United Kingdom	0.05	0.05	0.05
Turkey	0.21	0.19	0.19

Source: BSR Sustainability GmbH

Table 16-6: Estimated development of secondary aluminium production in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario 2005 – 2050

Country or Country group	2005	2020	2030	2040	2050
Austria	151	2005-2030: + 1.5% per year	2030-2050: + 1% per year		
Baltic States	not specified				
Belgium/Luxembourg	–	–	–	–	–
Bulgaria	8	20			40
Czech Republic	40		60		70
Denmark	20	20	20	20	20
Finland	35		44	44	44
France	222		270	270	270
Germany	712	2005-2050: + 7.5 per year			
Greece	9		11		13
Hungary	20		50		60
Ireland	–	–	–	–	–
Italy	654	2005-2030: + 6 per year	2030-2050: + 2 per year		
Malta/Cyprus	–	–	–	–	–
Netherlands	50	60	60	60	60
Norway	362		500		600
Poland	7	30		70	80
Portugal	18	2005-2030: + 0.5 per year	2030-2050: + 0.2 per year		
Romania	7	25		50	60
Slovakia	not specified				
Slovenia	not specified				
Spain	243		350		400
Sweden	32	2005-2030: + 0.0003 per year	2030-2050: + 0.0001 per year		
Switzerland	–	–	–	–	–
United Kingdom	205	2005-2030: + 1 per year	2030-2050: constant level		
Turkey	not specified	50			80

Source: BSR Sustainability GmbH

Assumptions about the drivers of cement production in Europe

The data between the reference points were calculated as linear increases or decreases. The figures for Austria, Denmark, Germany, the Netherlands and Norway show a constant level of cement production per capita throughout the whole period. In contrast, the cement production per capita increases to start with in Belgium/Luxembourg, the Czech Republic and Hungary and then levels out after 2040 (see Table 16-7). All other countries have a constant level of cement production per capita after 2030. The cement production per capita in Turkey gradually decreases from 2000 until 2050 assuming that the most intensive phase of construction occurs between 2000 and 2010.

Table 16-7: Estimated cement production in tonnes per capita in EU27 + Norway, Switzerland and Turkey, Reference Scenario 2005 – 2050

Country or Country group	2000	2020	2030	2040	2050
Austria	0.48	0.48	0.48	0.48	0.48
Baltic States	0.25			0.35	0.35
Belgium /Luxembourg	0.80		0.60	0.60	0.60
Bulgaria	0.30		0.38	0.38	0.38
Czech Republic	0.35	0.45		0.35	0.35
Denmark	0.38	0.38	0.38	0.38	0.38
Finland	0.25		0.35	0.35	0.35
France	0.34		0.38	0.38	0.38
Germany	0.40	0.40	0.40	0.40	0.40
Greece	1.42		0.50	0.50	0.50
Hungary	0.36	0.45		0.35	0.35
Ireland	0.96		0.40	0.40	0.40
Italy	0.75		0.60	0.60	0.60
Malta / Cyprus	2.10		1.50	1.50	1.50
Netherlands	0.20	0.20	0.20	0.20	0.20
Norway	0.40	0.40	0.40	0.40	0.40
Poland	0.30		0.35	0.35	0.35
Portugal	0.89		0.50	0.50	0.50
Romania	0.30		0.35	0.35	0.35
Slovakia	0.60		0.50	0.50	0.50
Slovenia	0.70		0.55	0.55	0.55
Spain	1.00		0.60	0.60	0.60
Sweden	0.30		0.38	0.38	0.38
Switzerland	0.55		0.50	0.50	0.50
United Kingdom	0.22		0.28	0.28	0.28
Turkey	0.50				0.40

Source: BSR Sustainability GmbH

Assumptions about the drivers of paper production in Europe

In the period *2030-2050*, the richer countries (Austria, Belgium/Luxembourg, Denmark, France, Finland, Germany, Greece, Ireland, Italy, the Netherlands, Spain, Portugal, Sweden, United Kingdom, Cyprus, Hungary, Poland, Norway and Switzerland) are calculated with lower elasticities of annual economic growth compared to the Central European countries (Czech Republic, the Baltic States, Malta, Slovakia, Slovenia, Bulgaria and Romania). It is estimated that the growth of paper production will slow down in the last decade even more in some countries. In Belgium/Luxembourg, Finland, France, Greece, Portugal, Norway and Switzerland, the elasticity is fixed at 10 % of the annual economic increase from 2040 on. The elasticity is reduced to 20 % of the annual economic growth in the Czech Republic, Estonia, Slovakia, Slovenia, Bulgaria and Romania. In contrast, some countries (Austria, Denmark, Germany, Ireland, Italy, Spain, Sweden, United Kingdom, Cyprus, Hungary, and Poland) show a constant level of paper industry growth.

Bulgaria, Latvia, Lithuania, Cyprus and Malta are exceptions, which are not in line with the developed paper production equation:

- Malta has no paper production.
- Cyprus (which started producing paper in 2003), Latvia and Lithuania do not seem to produce wood pulp or pulp according to the statistics. Therefore, these countries only produce paper on the basis of recycled paper and imported wood pulp or imported pulp. The paper production of Cyprus remains at a constant level of 5,000 tonnes per year from 2005 to 2030. Afterwards, paper production increases by about 100 tonnes per year for the next twenty years.
- Latvia: Paper production grows at a rate of 0.5 % per year from 2005 to 2030. For 2030-2050, the growth factor is 1 % per year. Lithuania: Paper production remains constant until 2030. Thereafter it grows at 0.4 % per year.
- Bulgaria: Paper production shows a constant increase of 2 % per year from 2005 to 2030. Between 2030 and 2050, the growth factor is only 1 % per year.

For the European countries, assumptions had to be made about the development of recycled paper, pulp and additives. These estimates were based on past developments in the composition of new paper (recycled paper, pulp, additives, mechanical pulp; see Table 16-8 based on the example of Germany) as well as on national sources projecting future shares of recycled paper.

Table 16-8: Consumption of the paper industry in Germany in percent (VDP, 2004)

Year	**Recycled paper**	**pulp**	**additives**	**mechanical pulp**
1985	39.0	30.0	18.0	13.0
2004	56.6	19.6	17.1	6.6

Source: BSR Sustainability GmbH

The insertion quota of additives is assumed to be 18.0 % in 2005. This quota decreases to 17.0 % in 2030 and 16.5 % in 2050. In countries which already have a high insertion quota of recycled paper of about 80 % (Denmark, Ireland, Spain, United Kingdom, Cyprus and Lithuania), the insertion quota of additives is estimated to be 15 % in 2005. This quota decreases to 14.4 % in 2030 and 14.0 % in 2050. The insertion quotas of recycled paper are taken from the German Association of the Paper Industry VDP or national sources. In countries with a high insertion quota of recycled paper (Denmark, Ireland, United Kingdom, Cyprus, Hungary, Latvia, Lithuania, Bulgaria and Switzerland), the maximum insertion quota was estimated to be constant at about 80 %.

Assumptions about the drivers of glass production in Europe

From 2030 to 2050, an elasticity of 20 % of the annual economic increase is assumed for the Western European countries (Austria, Belgium/Luxembourg, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Sweden, United Kingdom, Norway and Switzerland) and 25 % for the Central European countries (Greece, Portugal, Spain, Czech Republic, the Baltic States, Hungary, Slovakia, Slovenia, Bulgaria and Romania).

If glass production data were not available for intermittent years or countries, total glass was normally calculated as 26 % flat glass, 61 % container glass and 13 % other glass. Some countries show different subdivisions. This production structure was adopted from an older study of the glass market in Europe (see Table 16-9).

Table 16-9: Historical basis data for future glass production estimates

Country or country group	Basis year of production	Subdivision of glass (%)		
		flat	container	other
Bulgaria	container glass 2005 & flat glass 2006	26	61	13
Greece	container glass 2005	26	61	13
Netherlands	container glass 2005 & total glass 2003	12	74	14
Portugal	container glass 2003-2006	11	76	13
Spain	container glass 2002-2006	26	67	7
United Kingdom	container glass 2003-2006 & other glass 2005	26	61	13
Poland	container glass 2005-2006	26	61	13
Romania	container glass 2005	34	52	14
Switzerland	total glass 2005	26	61	13
Turkey	container glass 2003-2006, total glass 2000-2003 & other glass 2003	45	28	27

Source: BSR Sustainability GmbH

Detailed historical data of physical glass production (2000 - 2005), which were collected from different sources, are available for Austria (some data were calculated for the years 2001 - 2003), Belgium, France, Germany, Italy and the Czech Republic. Only the total glass production of the year 2000 was found for the following countries: Denmark, Finland (flat glass: 8 %, container glass: 46 %, other glass: 46 %), Ireland, Luxembourg, Sweden (flat glass: 55 %, container glass: 29 %, other glass: 16 %), the Baltic States, Hungary, Slovakia, Slovenia and Norway (flat glass: 9 %, container glass: 81 %, other glass: 10 %).

In Bulgaria (flat glass: 5 %, container glass: 94 %, other glass: 1 %), most glass factories have been closed for a number of years (British Glass: Overview of Glass Container – Production in the EU: 2006). Until 2005, the entire demand of Bulgaria was satisfied by imports from Turkey, France, the Czech Republic, Germany and China. At present, Sisecam is in the process of building several factories for various types of glass (British Glass: Overview of Glass Container – Production in the EU: 2006).

16.2.2 Production changes in energy-intensive products - Reference Scenario 2000 to 2050

Steel production

Table 16-10: Production of crude steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	5,710	6,050	5,540	5,000	4,040
Baltic States	500	480	440	400	340
Belgium/Luxembourg	14,210	13,590	13,510	13,350	12,670
Bulgaria	2,020	2,090	1,990	1,870	1,520
Czech Republic	6,210	5,760	5,300	4,770	3,800
Denmark	800	–	–	–	–
Finland	4,100	4,420	4,150	3,820	3,200
France	20,980	19,690	19,520	19,110	15,780
Germany	46,380	47,140	46,630	46,380	46,380
Greece	1,090	2,350	2,150	1,930	2,570
Hungary	1,870	1,990	1,930	1,840	1,650
Ireland	360	–	–	–	–
Italy	26,760	28,100	26,640	24,920	21,000
Malta/Cyprus	–	–	–	–	–
Netherlands	5,670	6,640	6,800	6,920	6,860
Norway	680	710	740	800	820
Poland	10,500	10,740	10,940	10,880	8,620
Portugal	1,090	910	990	1,050	1,150
Romania	4,670	6,110	5,990	5,790	5,030
Slovakia	3,730	4,810	4,120	3,360	1,880
Slovenia	520	660	670	660	490
Spain	15,920	17,600	17,770	17,600	17,020
Sweden	5,230	5,350	5,370	5,370	5,030
Switzerland	1,000	1,200	1,280	1,350	1,460
United Kingdom	15,160	13,740	13,980	14,250	13,430
EU27 + 2	**195,140**	**200,110**	**196,430**	**191,400**	**174,720**
Turkey	14,330	27,560	37,000	46,910	45,540
Total Europe	**209,460**	**227,670**	**233,430**	**238,300**	**220,270**

Source: BSR Sustainability GmbH

Table 16-11: Production of recycled steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	560	640	680	720	810
Baltic States	–	–	–	–	–
Belgium/Luxembourg	5,300	4,950	5,190	5,440	5,980
Bulgaria	600	760	810	860	970
Czech Republic	520	580	610	650	730
Denmark	800	–	–	–	–
Finland	970	1,460	1,550	1,650	1,860
France	8,490	7,520	7,990	8,480	9,560
Germany	13,320	14,080	14,950	15,870	17,890
Greece	1,090	2,300	2,370	2,440	2,590
Hungary	230	330	350	370	420
Ireland	360	–	–	–	–
Italy	16,010	18,030	19,140	20,200	19,000
Malta/Cyprus	–	–	–	–	–
Netherlands	160	150	150	160	190
Norway	680	710	740	780	820
Poland	3,290	3,560	3,780	4,010	4,520
Portugal	500	780	870	970	1,130
Romania	1,330	1,780	1,890	2,010	2,260
Slovakia	290	380	400	420	480
Slovenia	520	660	670	660	700
Spain	11,670	13,880	14,430	14,860	15,780
Sweden	1,950	1,820	1,930	2,050	2,310
Switzerland	1,000	1,200	1,280	1,350	1,460
United Kingdom	3,640	2,780	2,950	3,130	3,530
EU-27 + 2	**73,280**	**78,330**	**82,730**	**87,090**	**92,980**
Turkey	9,090	15,450	16,400	17,410	19,620
Total Europe	**82,370**	**93,780**	**99,130**	**104,500**	**112,600**

Source: BSR Sustainability GmbH

Table 16-12: Production of primary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	–	–	–	–	–
Baltic States	–	–	–	–	–
Belgium/Luxembourg	–	–	–	–	–
Bulgaria	–	–	–	–	–
Czech Republic	–	–	–	–	–
Denmark	–	–	–	–	–
Finland	–	–	–	–	–
France	440	450	460	470	470
Germany	640	620	550	490	360
Greece	160	170	170	170	170
Hungary	30	30	30	40	40
Ireland	–	–	–	–	–
Italy	190	200	200	200	200
Malta/Cyprus	–	–	–	–	–
Netherlands	300	340	350	350	350
Norway	1,030	1,580	1,990	2,400	3,000
Poland	50	60	60	60	60
Portugal	–	–	–	–	–
Romania	180	250	250	260	260
Slovakia	110	160	160	160	160
Slovenia	80	140	140	140	140
Spain	370	400	400	400	400
Sweden	100	110	110	110	110
Switzerland	40	50	50	50	50
United Kingdom	310	370	370	370	370
EU27 + 2	**4,020**	**4,900**	**5,290**	**5,650**	**6,130**
Turkey	60	60	70	70	90
Total Europe	**4,090**	**4,960**	**5,350**	**5,720**	**6,220**

Source: BSR Sustainability GmbH

Table 16-13: Production of secondary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario 2000 – 2050

Country or Country group	2000	2010	2020	2030	2050
Austria	160	160	170	190	210
Baltic States			not specified		
Belgium/Luxembourg	1	–	–	–	–
Bulgaria	10	10	20	30	40
Czech Republic	40	40	50	60	70
Denmark	30	20	30	20	20
Finland	40	40	40	40	40
France	270	230	250	270	270
Germany	570	750	820	900	1.050
Greece	10	10	10	10	10
Hungary	40	30	40	50	60
Ireland	–	–	–	–	–
Italy	600	680	740	800	840
Malta/Cyprus			not specified		
Netherlands	100	50	60	60	60
Norway	260	390	450	500	600
Poland	10	20	30	50	80
Portugal	20	20	30	30	30
Romania	2	10	30	40	60
Slovakia			not specified		
Slovenia			not specified		
Spain	240	260	310	350	400
Sweden	30	30	30	30	30
Switzerland	10	–	–	–	–
United Kingdom	240	210	220	230	230
EU27 + 2	**2,670**	**2,970**	**3,320**	**3,660**	**4,120**
Turkey	not specified	not specified	50	60	80
Total Europe	**not specified**	**not specified**	**3,370**	**3,720**	**4,200**

Source: BSR Sustainability GmbH

Table 16-14: Production of cement in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or Country group	2000	2010	2020	2030	2050
Austria	3,890	3,960	3,990	4,000	3,880
Baltic States	1,810	1,900	1,990	2,030	1,880
Belgium/Luxembourg	8,590	8,060	7,410	6,720	6,610
Bulgaria	2,400	2,440	2,430	2,370	1,930
Czech Republic	3,590	4,060	4,470	3,810	2,960
Denmark	2,030	2,090	2,140	2,190	2,220
Finland	1,290	1,500	1,710	1,910	1,860
France	20,140	21,720	23,060	24,190	23,960
Germany	32,940	33,080	32,910	32,610	31,510
Greece	15,580	12,470	9,050	5,560	5,370
Hungary	3,680	4,030	4,330	3,690	2,890
Ireland	3,650	3,420	2,870	2,100	2,300
Italy	43,290	40,720	37,140	33,250	30,550
Malta/Cyprus	2,470	2,450	2,380	2,230	2,400
Netherlands	3,180	3,320	3,400	3,460	3,430
Norway	1,800	1,890	1,980	2,080	2,170
Poland	11,610	12,160	12,580	12,700	11,180
Portugal	9,100	8,140	6,870	5,470	5,360
Romania	6,640	6,750	6,810	6,760	5,870
Slovakia	3,240	3,060	2,860	2,600	2,310
Slovenia	1,380	1,270	1,150	1,010	900
Spain	40,730	38,140	32,590	26,420	25,540
Sweden	2,670	3,000	3,360	3,720	3,820
Switzerland	3,940	3,890	3,800	3,700	3,620
United Kingdom	12,910	14,520	16,250	18,110	18,800
EU-27 + 2	**242,540**	**238,060**	**227,510**	**212,660**	**203,320**
Turkey	34,120	37,480	39,920	41,310	40,480
Total Europe	**276,650**	**275,540**	**267,430**	**253,960**	**243,810**

Source: BSR Sustainability GmbH

Table 16-15: Production of paper in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	4,390	5,370	6,030	6,700	8,380
Baltic States	120	220	220	230	370
Belgium/Luxembourg	1,730	1,900	2,250	2,620	3,170
Bulgaria	140	360	440	540	650
Czech Republic	540	800	850	860	1,190
Denmark	260	410	500	540	630
Finland	13,510	13,010	14,840	15,730	17,850
France	10,010	10,430	11,560	11,800	13,970
Germany	18,180	23,370	23,170	25,360	28,260
Greece	500	550	590	670	810
Hungary	510	600	620	700	1,040
Ireland	40	50	50	50	60
Italy	9,130	11,390	14,180	17,560	20,740
Malta/Cyprus	–	10	10	10	10
Netherlands	3,330	3,630	3,870	4,140	4,450
Norway	2,300	2,180	2,340	2,520	2,820
Poland	1,930	2,830	3,040	3,020	4,300
Portugal	1,290	1,830	2,570	3,370	4,380
Romania	340	400	640	880	1,220
Slovakia	930	890	910	860	1,720
Slovenia	410	650	650	640	800
Spain	4,770	5,870	8,090	8,630	10,910
Sweden	10,790	13,210	16,550	18,110	19,930
Switzerland	1,620	1,730	1,840	1,820	2,470
United Kingdom	6,610	6,670	6,600	6,770	8,310
EU27 + 2	**93,350**	**108,340**	**122,390**	**134,110**	**158,430**

Source: BSR Sustainability GmbH

Table 16-16: Production of total glass in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, Reference Scenario, 2000 – 2050

Country or country group	Glass category	2000	2010	2020	2030	2050
Austria	Total Glass	480	500	530	560	620
Baltic States	Total Glass	70	80	80	80	90
Belgium/Luxembourg	Total Glass	1,760	1,890	2,050	2,170	2,310
Bulgaria	Total Glass	240	770	900	1,090	1,280
Czech Republic	Total Glass	1,200	1,750	1,850	1,900	2,250
Denmark	Total Glass	190	190	210	220	240
Finland	Total Glass	140	150	160	160	170
France	Total Glass	5,530	5,780	6,130	6,390	6,760
Germany	Total Glass	7,680	7,000	7,350	7,700	8,070
Greece	Total Glass	290	330	340	370	400
Hungary	Total Glass	960	1,060	1,060	1,080	1,260
Ireland	Total Glass	190	240	270	290	320
Italy	Total Glass	4,910	5,550	6,010	6,350	6,860
Malta/Cyprus	Total Glass	–	–	–	–	–
Netherlands	Total Glass	1,360	980	1,060	1,140	1,270
Norway	Total Glass	90	80	80	80	80
Poland	Total Glass	1,580	1,910	1,940	1,930	2,160
Portugal	Total Glass	1,140	1,480	1,720	1,940	2,040
Romania	Total Glass	280	340	360	390	410
Slovakia	Total Glass	170	190	200	200	220
Slovenia	Total Glass	120	140	130	130	150
Spain	Total Glass	2,940	3,380	3,850	4,290	4,860
Sweden	Total Glass	350	380	430	440	470
Switzerland	Total Glass	410	320	320	320	390
United Kingdom	Total Glass	2,960	3,560	3,750	4,030	4,400
EU-27 + 2	**Total Glass**	**35,020**	**38,060**	**40,790**	**43,230**	**47,080**
Turkey	Total Glass	1,600	2,240	3,010	4,050	6,010
Total Europe	**Total Glass**	**36,620**	**40,300**	**43,800**	**47,280**	**53,100**

Source: BSR Sustainability GmbH

16.2.3 Production in energy-intensive products - 2°C Scenario – 2000 to 2050

Table 16-17: Production of crude steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	5,710	6,030	5,340	4,590	3,280
Baltic States	500	0	0	0	0
Belgium/Luxembourg	14,210	13,540	12,930	12,120	10,090
Bulgaria	2,020	2,080	1,900	1,700	1,190
Czech Republic	6,210	5,740	5,110	4,380	3,090
Denmark	800	0	0	0	0
Finland	4,100	4,410	3,970	3,460	2,520
France	20,980	19,620	18,680	17,330	12,440
Germany	46,380	46,970	44,710	42,250	37,170
Greece	1,090	2,290	2,240	2,160	1,980
Hungary	1,870	1,990	1,850	1,690	1,340
Ireland	360	0	0	0	0
Italy	26,760	27,980	25,320	22,230	16,170
Malta/Cyprus	–	0	0	0	0
Netherlands	5,670	6,620	6,570	6,400	5,650
Norway	680	710	700	690	620
Poland	10,500	10,700	10,480	9,900	6,830
Portugal	1,090	770	820	860	860
Romania	4,670	6,090	5,740	5,280	4,010
Slovakia	3,730	4,800	3,970	3,090	1,520
Slovenia	520	650	630	590	540
Spain	15,920	17,520	16,850	15,670	13,080
Sweden	5,230	5,330	5,150	4,880	4,010
Switzerland	1,000	1,190	1,210	1,190	1,120
United Kingdom	15,160	13,690	13,440	13,060	10,860
EU27 + 2	**195,140**	**198,690**	**187,610**	**173,500**	**138,380**
Turkey	14,330	27,450	35,380	42,680	36,380
Total Europe	**209,460**	**226,140**	**222,980**	**216,180**	**174,750**

Source: BSR Sustainability GmbH

Table 16-18: Production of recycled steel in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	560	640	640	640	620
Baltic States	–	0	0	0	0
Belgium/Luxembourg	5,300	4,930	4,900	4,810	4,570
Bulgaria	600	760	760	760	740
Czech Republic	520	570	580	570	560
Denmark	800	0	0	0	0
Finland	970	1,460	1,470	1,460	1,420
France	8,490	7,480	7,540	7,490	7,300
Germany	13,320	14,010	14,110	14,030	13,670
Greece	1,090	2,290	2,240	2,160	1,980
Hungary	230	330	330	330	320
Ireland	360	0	0	0	0
Italy	16,010	17,940	18,070	17,860	14,520
Malta/Cyprus	–	0	0	0	0
Netherlands	160	150	150	150	140
Norway	680	710	700	690	620
Poland	3,290	3,540	3,560	3,540	3,450
Portugal	500	770	820	860	860
Romania	1,330	1,770	1,780	1,770	1,730
Slovakia	290	370	380	380	370
Slovenia	520	650	630	590	540
Spain	11,670	13,810	13,620	13,140	12,060
Sweden	1,950	1,810	1,830	1,820	1,770
Switzerland	1,000	1,190	1,210	1,190	1,110
United Kingdom	3,640	2,770	2,790	2,770	2,700
EU27 + 2	**73,280**	**77,940**	**78,100**	**76,990**	**71,040**
Turkey	9,090	15,370	15,480	15,390	14,990
Total Europe	**82,370**	**93,310**	**93,580**	**92,380**	**86,030**

Source: BSR Sustainability GmbH

Table 16-19: Production of primary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	–	0	0	0	0
Baltic States	–	0	0	0	0
Belgium/Luxembourg	–	0	0	0	0
Bulgaria	–	0	0	0	0
Czech Republic	–	0	0	0	0
Denmark	–	0	0	0	0
Finland	–	0	0	0	0
France	440	450	450	450	420
Germany	640	610	540	460	320
Greece	160	170	170	160	150
Hungary	30	30	30	30	30
Ireland	–	0	0	0	0
Italy	190	200	200	190	180
Malta/Cyprus	–	0	0	0	0
Netherlands	300	340	340	330	310
Norway	1,030	1,580	1,950	2,270	2,660
Poland	50	60	60	60	50
Portugal	–	0	0	0	0
Romania	180	250	250	250	230
Slovakia	110	160	160	150	140
Slovenia	80	140	140	130	120
Spain	370	400	390	380	360
Sweden	100	110	110	100	100
Switzerland	40	50	40	40	40
United Kingdom	310	370	360	350	330
EU27 + 2	**4,020**	**4,890**	**5,170**	**5,350**	**5,430**
Turkey	60	60	60	70	80
Total Europe	**4,090**	**4,950**	**5,230**	**5,420**	**5,510**

Source: BSR Sustainability GmbH

Table 16-20: Production of secondary aluminium in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	160	160	170	180	190
Baltic States			not specified		
Belgium/Luxembourg	1	0	0	0	0
Bulgaria	10	10	20	30	40
Czech Republic	40	40	50	60	60
Denmark	30	20	20	20	20
Finland	40	40	40	40	40
France	270	230	250	260	240
Germany	570	750	810	860	940
Greece	10	10	10	10	10
Hungary	40	30	40	50	50
Ireland	–	0	0	0	0
Italy	600	680	730	770	760
Malta/Cyprus			not specified		
Netherlands	100	50	60	60	50
Norway	260	390	440	480	540
Poland	10	20	30	50	70
Portugal	20	20	30	30	30
Romania	2	10	20	40	50
Slovakia			not specified		
Slovenia			not specified		
Spain	240	260	300	340	360
Sweden	30	30	30	30	30
Switzerland	10	0	0	0	0
United Kingdom	240	210	220	200	210
EU27 + 2	**2,670**	**2,960**	**3,250**	**3,510**	**3,700**
Turkey	not specified	not specified	50	60	70
Total Europe	**not specified**	**not specified**	***3,290***	**3,570**	**3,770**

Source: BSR Sustainability GmbH

Table 16-21: Production of cement in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	3,890	3,940	3,770	3,580	3,080
Baltic States	1,810	1,890	1,880	1,810	1,490
Belgium/Luxembourg	8,590	8,010	7,010	6,010	5,260
Bulgaria	2,400	2,420	2,290	2,130	1,530
Czech Republic	3,590	4,040	4,220	3,410	2,350
Denmark	2,030	2,080	2,020	1,960	1,770
Finland	1,290	1,490	1,620	1,710	1,480
France	20,140	21,610	21,790	21,650	19,050
Germany	32,940	32,920	31,100	29,180	25,050
Greece	15,580	12,410	8,550	4,970	4,270
Hungary	3,680	4,010	4,090	3,300	2,300
Ireland	3,650	3,400	2,710	1,880	1,830
Italy	43,290	40,520	35,090	29,760	24,290
Malta/Cyprus	2,470	2,440	2,250	1,990	1,910
Netherlands	3,180	3,300	3,210	3,100	2,730
Norway	1,800	1,880	1,880	1,860	1,730
Poland	11,610	12,100	11,890	11,370	8,890
Portugal	9,100	8,100	6,490	4,890	4,260
Romania	6,640	6,710	6,430	6,050	4,660
Slovakia	3,240	3,050	2,700	2,320	1,840
Slovenia	1,380	1,270	1,090	910	710
Spain	40,730	37,950	30,800	23,650	20,300
Sweden	2,670	2,980	3,170	3,330	3,040
Switzerland	3,940	3,870	3,600	3,310	2,880
United Kingdom	12,910	14,450	15,350	16,210	14,950
EU27 + 2	**242,540**	**236,870**	**215,000**	**190,330**	**161,640**
Turkey	34,120	37,290	37,720	36,970	32,180
Total Europe	**276,650**	**274,160**	**252,720**	**227,300**	**193,830**

Source: BSR Sustainability GmbH

Table 16-22: Production of paper in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	2000	2010	2020	2030	2050
Austria	4,390	5,350	5,690	5,920	6,220
Baltic States	120	220	210	210	280
Belgium/Luxembourg	1,730	1,890	2,120	2,320	2,360
Bulgaria	140	360	410	470	490
Czech Republic	540	790	800	760	890
Denmark	260	410	470	470	470
Finland	13,510	12,940	14,010	13,890	13,260
France	10,010	10,380	10,920	10,420	10,380
Germany	18,180	23,250	21,870	22,400	21,000
Greece	500	550	560	590	600
Hungary	510	590	580	620	780
Ireland	40	50	50	50	40
Italy	9,130	11,330	13,380	15,510	15,410
Malta/Cyprus	–	10	10	4	10
Netherlands	3,330	3,610	3,660	3,660	3,300
Norway	2,300	2,170	2,210	2,220	2,090
Poland	1,930	2,810	2,870	2,670	3,200
Portugal	1,290	1,820	2,430	2,970	3,260
Romania	340	390	600	780	910
Slovakia	930	890	860	760	1,280
Slovenia	410	650	610	570	590
Spain	4,770	5,840	7,630	7,620	8,100
Sweden	10,790	13,150	15,630	15,990	14,810
Switzerland	1,620	1,720	1,730	1,610	1,840
United Kingdom	6,610	6,630	6,230	5,980	6,170
EU27 + 2	**93,350**	**107,790**	**115,540**	**118,420**	**117,720**

Source: BSR Sustainability GmbH

Table 16-23: Production of total glass in EU27 + Norway, Switzerland and Turkey in 1000 tonnes, 2°C Scenario, 2000 – 2050

Country or country group	Glass category	2000	2010	2020	2030	2050
Austria	Total Glass	480	500	520	510	480
Baltic States	Total Glass	70	80	80	80	80
Belgium/Luxembourg	Total Glass	1,760	1,890	2,070	2,220	2,460
Bulgaria	Total Glass	240	760	850	950	960
Czech Republic	Total Glass	1,200	1,750	1,880	1,970	2,220
Denmark	Total Glass	190	190	200	210	200
Finland	Total Glass	140	150	150	150	150
France	Total Glass	5,530	5,760	5,960	5,950	5,580
Germany	Total Glass	7,680	6,980	7,230	7,330	7,060
Greece	Total Glass	290	330	340	350	340
Hungary	Total Glass	960	1,060	1,100	1,120	1,210
Ireland	Total Glass	190	240	260	270	260
Italy	Total Glass	4,910	5,530	5,810	5,850	5,530
Malta/Cyprus	Total Glass	–	0	0	0	0
Netherlands	Total Glass	1,360	840	880	890	840
Norway	Total Glass	90	80	80	70	60
Poland	Total Glass	1,580	2,030	2,080	2,050	2,100
Portugal	Total Glass	1,140	1,490	1,650	1,730	1,530
Romania	Total Glass	280	390	420	430	430
Slovakia	Total Glass	170	190	200	200	200
Slovenia	Total Glass	120	130	130	130	130
Spain	Total Glass	2,940	3,340	3,660	3,840	3,780
Sweden	Total Glass	350	380	420	440	480
Switzerland	Total Glass	410	320	330	330	350
United Kingdom	Total Glass	2,960	3,560	3,700	3,800	3,750
EU27 + 2	**Total Glass**	**35,020**	**37,980**	**40,000**	**40,880**	**40,190**
Turkey	Total Glass	1,600	2,220	2,720	3,310	4,220
Total Europe	**Total Glass**	**36,620**	**40,200**	**42,720**	**44,180**	**44,410**

Source: BSR Sustainability GmbH

16.3 Economic sectors used in the ASTRA model

The national economies of the EU27+2 countries modelled by the ASTRA model are divided into 25 economic sectors according to the NACE-CLIO categorisation (General Industrial Classification of Economic Activities in the European Communities - version used for the input-output tables). It includes 14 manufacturing sectors, 9 service sectors and 2 other sectors, which are presented in the following list:

Manufacturing sectors:

- Energy, gas and water
- Ferrous and non-ferrous ores and metals
- Non-metallic mineral products
- Chemical products
- Metal products except machinery
- Agricultural and industrial machinery
- Optical goods, office+data processing mach.
- Electrical goods
- Transport equipment
- Food, beverages, tobacco
- Textiles and clothing, leather and footwear
- Paper and printing products
- Rubber and plastic products
- Other manufacturing products

Service sectors:

- Recovery, repair services, wholesale, retail
- Lodging and catering services
- Inland transport services
- Maritime and air transport services
- Auxiliary transport services
- Communication services
- Services of credit and insurance institutions
- Other market services
- Non-market services

Other sectors:

- Agriculture, forestry and fishery products
- Building and construction

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